Scientific Apparatus

SPECIAL LOAN COLLECTION 1876

SOUTH KENSINGTON MUSEUM

SCIENCE HANDBOOK

Science

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SOUTH KENSINGTON MUSEUM SCIENCE HANDBOOKS.

SPECIAL LOAN COLLECTION OF SCIENTIFIC APPARATUS

1876.

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…FLOOR

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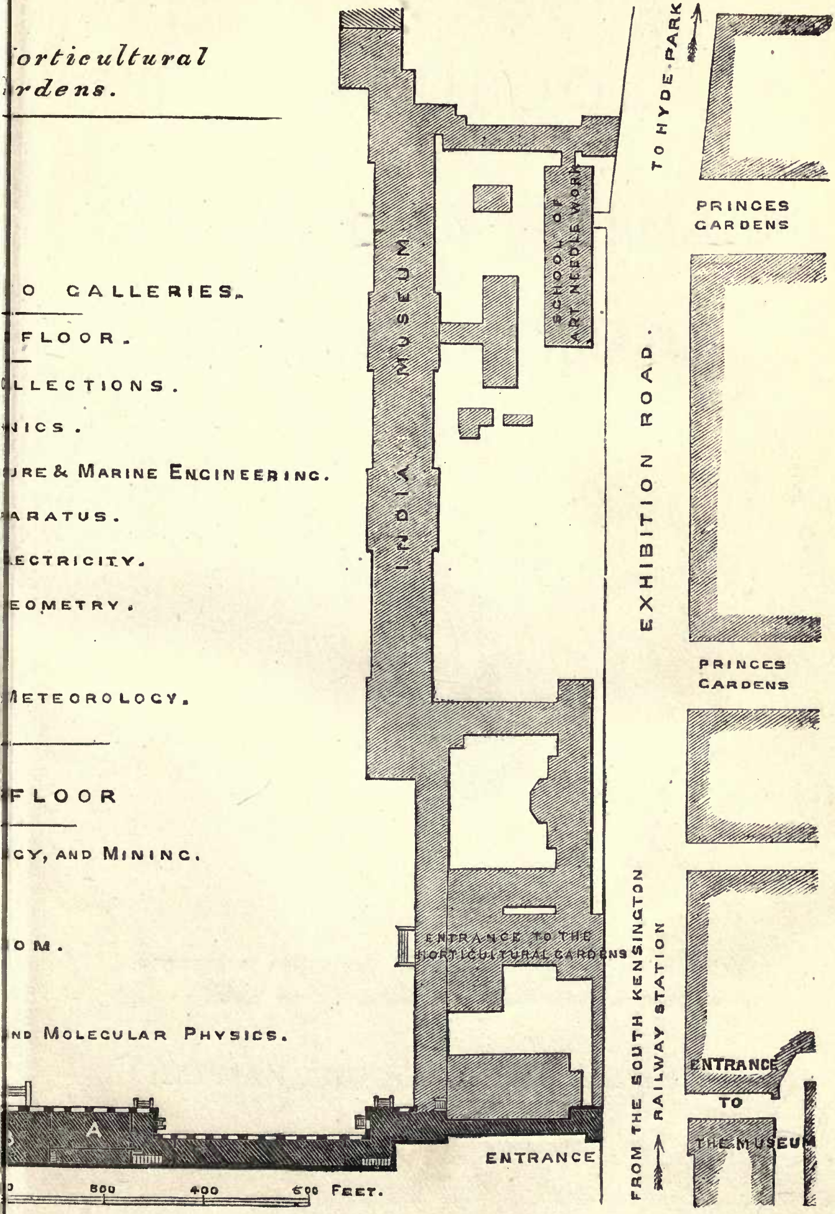
…ND MOLECULAR PHYSICS.



SOUTH KENSINGTON MUSEUM.

HANDBOOK

TO THE

SPECIAL LOAN COLLECTION

OF

SCIENTIFIC APPARATUS

1876.

Prepared at the request of the Lords of the Committee of Council on Education, and Published for them

BY

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INTRODUCTION.

By Minute dated 22nd January, 1875, the Lords of the Committee of Council on Education approved of a proposal to form a Loan Collection of Scientific Apparatus, which was to include not only apparatus for teaching and for investigation, but also such as possessed historic interest on account of the persons by whom, or the researches in which, it had been employed. Their Lordships then invited some of the leading men of science of the country—the Presidents of the learned Societies and others—to act on a Committee to consider the matter, and aid them with their advice. This Committee, to whose exertions the formation of the Collection is so largely due, consisted of

The Right Hon. the Lord Chancellor.
Professor F. A. Abel, F.R.S., President of the Chemical Society.
The Right Hon. Lord Aberdare, President of the Horticultural Society.
Capt. W. de W. Abney, R.E.
Professor H. W. Acland, M.D., F.R.S., President of the Medical Council of the United Kingdom.
Professor J. C. Adams, M.A., F.R.S.
Professor W. G. Adams, M.A., F.R.S.
Sir G. B. Airy, K.C.B., D.C.L., F.R.S., the Astronomer Royal.
Dr. G. J. Allman, F.R.S., President of the Linnæan Society.
Mr. J. Anderson, LL.D., C.E.
Mr. D. T. Ansted, M.A., F.R.S.
Professor E. Atkinson, Ph. D.
Professor R. Stawell Ball, LL.D., F.R.S.
Professor W. F. Barrett.
Rev. A. Barry, D.D.
Mr. W. B. Baskcomb.
Mr. H. Bauerman.
Mr. G. Bentham, F.R.S.
Mr. Hugh Birley, M.P.
Professor Bloxam.
Major Bolton.
Professor F. A. Bradley.
Mr. F. J. Bramwell, F.R.S.
Mr. T. Brassey, M.P.
Mr. H. W. Bristow, F.R.S.
Mr. C. Brooke, M.A., F.R.S.
Mr. G. Busk, F.R.S.
Major-General Cameron, C.B., F.R.S.
Dr. W. B. Carpenter, C.B., F.R.S.
Mr. C. O. F. Cator.

Mr. W. Chappell.
Mr. H. W. Chisholm, Warden of the Standards.
Lord Alfred Churchill, Chairman of Council of Society of Arts.
Mr. G. T. Clark.
Mr. Latimer Clark.
Professor R. Bellamy Clifton, M.A., F.R.S.
Sir Henry Cole, K.C.B.
Vice-Admiral Sir R. Collinson, K.C.B., Deputy Master of the Trinity House.
Dr. Debus, F.R.S.
Mr. Warren De La Rue, D.C.L., F.R.S.
Mr. G. Dixon, M.P.
Professor P. M. Duncan, M.B., F.R.S., President of the Geological Society.
Professor W. T. Thiselton Dyer, M.A., B. Sc.
Major-General F. Eardley-Wilmot, R.A., F.R.S.
Mr. H. S. Eaton, President of the Meteorological Society.
Sir P. De M. G. Egerton, Bart., M.P., F.R.S.
Mr. R. Etheridge, F.R.S.
Captain Evans, R.N., C.B., F.R.S., Hydrographer of the Navy.
Mr. J. Evans, F.R.S.
Professor W. H. Flower, F.R.S.
Mr. D. Forbes, F.R.S.
Professor G. Carey Foster, B.A., F.R.S., President of the Physical Society.
Professor Michael Foster, M.D., F.R.S.
Colonel Lane Fox, President of the Anthropological Institute.
Professor Frankland, Ph. D., D.C.L., F.R.S.
Mr. A. H. Garrod, M.A.
Dr. Gilbert, F.R.S.
Dr. J. H. Gladstone, F.R.S.
Mr. D. Glasgow.
Professor Goodeve, M.A.
Mr. A. C. L. G. Günther, M.A., M.D., F.R.S.
Professor Guthrie, Ph. D., F.R.S.
Mr. J. Baillie-Hamilton.
The Right Hon. Lord Hampton, G.C.B., F.R.S., President of the Institute of Naval Architects.
Mr. T. E. Harrison, President of the Institution of Civil Engineers.
Sir J. Hawkshaw, F.R.S.
Mr. T. Hawksley, Fresident of the Institute of Mechanical Engineers.
The Hon. Alan Herbert.
Mr. J. Hick, M.P.
Dr. J. D. Hooker, C.B., President of the Royal Society.
Mr. J. Hopkinson, B.A., D. Sc.
Mr. W. Huggins, D.C.L., F.R.S., President of the Royal Astronomical Society.
Professor W. Hughes.
Professor T. H. Huxley, LL.D., Sec. R.S.
Lieut.-General Sir H. James, R.E., F.R.S.
Rev. J. H. Jellett, B.D.
Professor E. Ray Lankester, M.A., F.R.S.
Lord Lindsay, M.P.
Mr. J. Norman Lockyer, F.R.S.
Rev. R. Main, M.A., F.R.S.
Dr. R. J. Mann.
Mr. N. Story-Maskelyne, M.A., F.R.S.
Professor J. Clerk Maxwell, M.A., F.R.S.
Mr. C. W. Merrifield, F.R.S.
Professor Miller, M.A., LL.D., F.R.S.
Professor Morris.
Mr. A. J. Mundella, M.P.
Professor Odling, M.A., F.R.S.
Mr. W. K. Parker, F.R.S.
Dr. Percy, F.R.S.

Mr. J. A. Phillips.
The Right Hon. Lyon Playfair, C.B., M.P., F.R.S.
Dr. Pole, F.R.S.
Professor Prestwich, F.R.S.
Professor A. C. Ramsay, LL.D., F.R.S.
Major-General Sir H. C. Rawlinson, K.C.B., F.R.S., President of the Royal Geographical Society.
The Right Hon. Lord Rayleigh, F.R.S.
Professor A. W. Reinold, M.A.
Professor Roscoe, Ph. D., F.R.S.
The Right Hon. the Earl of Rosse, D.C.L., F.R.S.
Mr. G. W. Royston-Pigott, M.A., M.D., F.R.S.
Mr. J. Scott Russell, F.R.S.
Dr. W. J. Russell, F.R.S.
Professor W. Rutherford, M.D.
Mr. B. Samuelson, M.P.
Professor J. S. Burdon Sanderson, M.D., F.R.S.
Mr. T. Savage, M.A.
Mr. R. H. Scott, M.A., F.R.S.
Major Seddon, R.E.
Professor Shelley.
Sir. J. P. Kay-Shuttleworth, Bart.
Mr. C. W. Siemens, D.C.L., F.R.S.
Professor H. J. S. Smith, M.A., F.R.S.
Mr. W. Warington Smyth, M.A., F.R.S.
Mr. H. C. Sorby, F.R.S., President of the Royal Microscopical Society.
Mr. W. Spottiswoode, M.A., Treasurer Royal Society.
Mr. G. R. Stephenson.
Professor Balfour Stewart, LL.D., F.R.S.
Dr. W. H. Stone.
Major - General Strachey, C.S.I., F.R.S.
Lieut.-Col. Strange, F.R.S.
Professor P. G. Tait, M.A.
Mr. J. Torr, M.P.
Rev. J. F. Twisden, M.A.
Professor Tyndall, LL.D., F.R.S.
Professor W. C. Unwin, B. Sc.
Mr. C.V. Walker, F.R.S., President of Society of Telegraphic Engineers.
Mr. F. H. Wenham.
Sir C. Wheatstone, F.R.S. (since deceased).
Sir. J. Whitworth, Bart., F.R.S.
Professor Williamson, Ph. D., F.R.S.
Mr. Bennet Woodcroft, F.R.S.
Dr. J. Woolley.
Colonel H. Stuart Wortley.

The first meeting of this Committee was held on the 13th February, 1875; the number of those who were present showing the interest already felt in the subject. The Lord President of the Council, the Duke of Richmond, and the Vice-President, Viscount Sandon, in explaining the objects of the Collection, took occasion to refer to the recommendations of the Royal Commission on Scientific Instruction, with regard to the creation of a Science Museum.

Their Lordships stated their conviction that the development of the Educational, and certain other Departments of the South Kensington Museum, and their enlargement into a Museum

somewhat of the nature of the *Conservatoire des Arts et Métiers* in Paris, and other similar institutions on the Continent, would tend to the advancement of science, and be of great service to the industrial progress of this country. While expressing their hope that the Loan Collection might forward this desirable object, their Lordships guarded themselves against committing Her Majesty's Government, which had not yet fully considered the subject, to any definite scheme.

On the motion of the President of the Royal Society, Dr. Hooker, it was unanimously resolved by the meeting that an exhibition such as that proposed would be most instructive and valuable.

The question of the limits of the collection were discussed, and Sub-Committees were appointed to consider the limitations it might be desirable to place on the term "scientific apparatus" in the respective sections, while bearing in mind the space disposable for the exhibition in the Museum. As a provisional arrangement five Sub-Committees of sections were appointed to whom it was left to suggest such modifications in classification as might be found advisable.

The sections were—

1. Mechanics (including pure and applied mathematics).
2. Physics.
3. Chemistry (including metallurgy).
4. Geology, Mineralogy, and Geography.
5. Biology.

The Committees for the several sections are given at page xxv.

The question of classification, having been carefully considered at numerous meetings of these Sub-Committees, was brought before the general Committee on the 12th May, and the several schemes were referred to a special Sub-Committee, formed of three members from each sectional Sub-Committee. It was also decided to postpone the exhibition, which it was originally intended to open in June, 1875, to March, 1876. The large number

of objects sent from abroad, and the late period of their arrival, have necessitated a further postponement of the opening to May, 1876.

The Sub-Committee appointed to revise and report on the classification of the Collection after three meetings, under the chairmanship of the President of the Royal Society, submitted a scheme of classification to the General Committee on June 22nd. After having been carefully considered, it was, with some slight alterations, approved, and is given at page xix. This programme was immediately issued, and the classification into sections is that adopted for the catalogue and exhibition, though the nature of the Galleries has necessitated some alteration in the order of the sections.

It had been the intention from the first to give the Loan Collection an International character, so as to afford men of science and those interested in education an opportunity of seeing what was being done by other countries than their own in the production of apparatus, both for research and for instruction—an opportunity which it was hoped would be of advantage also to the makers of instruments. As soon therefore as the programme had been definitely settled, steps were taken to interest foreign countries in the Exhibition; and it was determined to obtain the co-operation of men of science on the Continent, who, while acting as members of the General Committee, should form special Sub-Committees charged with the due representation of the science of their respective countries.

It was necessary to take special precautions to prevent misunderstanding as to the character of the Collection. The mention of internationality at once suggested the idea of an International Exhibition similar in its character and arrangements to the numerous Industrial Exhibitions which have been held in various countries. A wrong impression of this kind would have entailed serious inconvenience.

In International Exhibitions a certain amount of space is allotted to each country. These spaces are then divided by the Commis-

sioners of each country among its exhibitors, who display their objects—subject to certain general rules of classification—as they consider most advantageous, retaining the custody of their own property. The expenses of transport, arrangement, etc., are borne by the countries who exhibit. And the Exhibitions appeal naturally, more or less exclusively, to the industrial or trade-producing interests of those countries.

This was not the idea of the proposed Loan Collection at South Kensington. For that Collection it was desired to obtain not only apparatus and objects from manufacturers, but also objects of historic interest from museums and private cabinets, where they are treasured as sacred relics, as well as apparatus in present use in the Laboratories of Professors. The transport of all objects was undertaken by the English Government, and they were to be handed over absolutely to the custody of the Science and Art Department for exhibition; the arrangement being not by countries but strictly according to the general classification.

So soon as the object and scope of the Collection were thoroughly understood, the Committee of Council on Education met with the most gratifying responses to their invitations, which were communicated officially through the Foreign Office. Her Majesty's Ministers at Paris, Berlin, St. Petersburgh, Vienna, Florence, Brussels, the Hague, Stockholm, Madrid, Berne, and Washington, have personally interested themselves in the matter; and the Foreign Governments have afforded every facility and encouragement in forwarding this strictly international undertaking. The subjoined list of the foreign members of the General Committee speaks for itself, by the eminence and European reputation of its members.

BELGIUM.

M. Stas, Membre de l'Académie Royale (President).

M. le Général Brialmont, Président de l'Académie Royale et Inspecteur Général du Génie.

M. Dewalque, Membre de l'Académie Royale, Professeur de Géologie et de Minéralogie à l'Université de Liége.

M. Maus, Membre de l'Académie, Inspecteur Général des Ponts et Chaussées.
M. Plateau, Membre de l'Académie Royale, F.R.S.
M. Schwann, Membre de l'Académie Royale, Professeur à l'Université de Liége.
M. Van Beneden, Membre de l'Académie et Professeur à l'Université de Louvain, F.R.S.
M. le Général Liagre, Secrétaire perpétuel de l'Académie Royale, et Commandant et Directeur des Études de l'École Militaire (Secretary).

FRANCE.

M. le Général Arthur Jules Morin, Membre de l'Académie des Sciences, Directeur du Conservatoire des Arts et Métiers (President).
M. Alexre. Edmond Becquerel, Membre de l'Académie des Sciences, Professeur au Conservatoire des Arts et Métiers, F.R.S.
M. Henri Marie Bouley, Membre de l'Académie des Sciences, Inspecteur Général des Écoles Vétérinaires.
M. Gabriel Auguste Daubrée, Membre de l'Académie des Sciences, Directeur de l'École des Mines.
M. Jean Louis Armand de Quatrefages de Bréau, Membre de l'Académie des Sciences, Professeur au Museum d'Histoire Naturelle.
M. Jean Baptiste Dumas, Secrétaire Perpétuel de l'Académie des Sciences, F.R.S.
M. Hervé Auguste Etienne Albans Faye, Membre de l'Académie des Sciences, Président du Bureau des Longitudes.
M. Edmond Frémy, Membre de l'Académie des Sciences, Professeur au Museum d'Histoire Naturelle.
M. Jules Célestin Jamin, Membre de l'Académie des Sciences, Professeur à l'École Polytechnique.
M. Urbain Jean Joseph La Verrier, Membre de l'Académie des Sciences, Directeur de l'Observatoire, F.R.S.
M. Eugène Melchior Peligot, Membre de l'Académie des Sciences, Directeur des Essais à la Monnaie.
M. Henri Edouard Tresca, Membre de l'Académie des Sciences, Sous-Directeur du Conservatoire des Arts et Métiers (Secretary).

GERMANY.

I.—Berlin Committee.

Dr. A. W. Hofmann, Professor of Chemistry, F.R.S. (President).
Dr. Beyrich, Professor of Geology.
Dr. du Bois-Reymond, Professor of Physiology.
Dr. Dove, Professor of Physics, F.R.S.
Dr. Förster, Director of the Observatory.
Dr. Hagen, President of the Board of Works.
T. G. Halske, Telegraphic Engineer.
Dr. Hauchecorne, Director of the School of Mines.

Dr. Helmholtz, Professor of Physics, F.R.S.
Dr. Kiepert, Professor of Geography.
Dr. G. Kirchhoff, Professor of Physics, F.R.S.
Dr. Kronecker, Professor of Mathematics.
Dr. C. D. Martius, Chemist.
Von Morozowicz, General.
Dr. Neumayer, Hydrographer of the Imperial Admiralty.
Dr. Reuleaux, Director of the Polytechnic Academy.
Dr. Shellbach, Professor of Mathematics.
Dr. W. Siemens, Telegraphic Engineer.
Dr. Virchow, Professor of Pathology.
Dr. C. H. Vogel, Astronomer.
Dr. Websky, Professor of Mineralogy.

II.—Committee representing other Cities and Towns of Germany.

Dr. Von Babo, Professor of Chemistry, Freiburg.
Dr. Beetz, Professor of Physics, Munich.
Dr. Buff, Professor of Physics, Giessen.
Dr. Clausius, Professor of Physics, Bonn, F.R.S.
His Excellency Dr. Von Dechen, Director of the Mining Department, Bonn.
Dr. Von Fehling, Professor of Chemistry, Stuttgart.
Dr. Von Feilitzsch, Professor of Physics, Greifswald.
Dr. Graebe, Professor of Chemistry, Königsberg.
Dr. Von Groddeck, Director of the School of Mines, Klausthal.
Dr. Heeren, Professor of Chemistry, Hanover.
Dr. Hittorf, Professor of Chemistry, Münster.
Dr. Karsten, Professor of Physics, Kiel.
Dr. Karsten, Professor of Physics, Rostock.
Dr. Knapp, Professor of Chemistry, Braunschweig.
Dr. Knoblauch, Professor of Physics, Halle.
Dr. Kölliker, Professor of Physiology, Würzburg, F.R.S.
Dr. Kundt, Professor of Physics, Strasburg.
Dr. Launhardt, Director of the Polytechnic School, Hanover.
Dr. Möhl, Cassel.
Dr. Poleck, Professor of Chemistry, Breslau.
Dr. Preyer, Professor of Physiology, Jena.
Dr. Von Quintus-Icilius, Professor of Physics, Hanover.
Dr. Reusch, Professor of Physics, Tübingen.
Dr. Romberg, Professor in the Nautical School, Bremen.
Dr. Rosenthal, Professor of Physiology, Erlangen.
Dr. Rümker, Director of the Observatory, Hamburg.
Dr. Serlo, Director of the Mining Department, Breslau.
Dr. C. Von Siemens, Professor in the Agricultural Academy, Hohenheim
His Excellency Dr. Von Steinbeis, President, Stuttgart.
Dr. W. Weber, Professor of Physics, Göttingen, F.R.S.
Dr. Wiedemann, Professor of Physical Chemistry, Leipzig.
Dr. Winkler, Professor of Metallurgy, Freiberg.
Dr. Wöhler, Professor of Chemisty, Göttingen, F.R.S.

Dr. Wüllner, Professor of Physics, Aachen.
Dr. Zeuner, Director of the Polytechnic School, Dresden.
Dr. Zetzsche, Director of the Polytechnic School, Chemnitz.

ITALY.

Il Com. Blaserna, Professor of Physics and Rector of the Royal University of Rome.
Il Com. Cantoni, Professor of Physics at the Royal University of Pavia.
Il Cav. Respighi, Professor of Astronomy in the Royal University of Rome, and Director of the Observatory of the Campidoglio.

THE NETHERLANDS.

Professor Dr. P. L. Rijke, Conseiller d'État (President).
Professor Dr. H. G. de Sande Bakhuyzen.
Professor Dr. C. H. D. Buys Ballot.
Professor Dr. J. Bosscha.
Professor Dr. F. C. Donders, F.R.S., President of the Royal Academy of Science, Amsterdam.
Professor Dr. J. W. Gunning.
Professor Dr. R. A. Mees.
Professor Dr. V. S. M. Van der Willigen.
Dr. D. de Loos, Director of the Secondary Town-School of Leyden (Secretary).

NORWAY.

Professor Esmark.
Herr Mohn, Director of the Meteorological Institute of Norway.
Professor Waage.

RUSSIA.

M. Struve, Conseiller Privé Directeur de l'Observatoire Central Nicolas (President).
M. Ovsiannikow, membre de l'Académie.
M. Gadolin, membre de l'Académie.
M. Gruber, Professeur de l'Académie de Médécine et de Chirurgerie.
M. Stubendorf, Colonel d'État-Major.
M. Wyschnegradsky, Professeur de l'Institut technologique.
M. Beilstein, Professeur de l'Institut technologique.
M. Barbot de Marny, Professeur de l'Institut des Mines.
M. Koulibine, Professeur de l'Institut des Mines.

SWITZERLAND.

Professor E. Wartmann (President).
Professor J. Amsler Laffon.
Professor D. Colladon-Ador.
Professor Dr. F. A. Forel.
Professor Dr. E. Hagenbach-Bischoff.
Professor Ad. Hirsch.
Professor Albert Mousson.
M. E. Sarasin-Diodati.
Professor L. Soret.
Colonel Gautier (Secretary).

AUSTRIA AND HUNGARY.

The Minister of Public Instruction has appointed Sectionschef Fidler to organize the contributions from these countries.

SPAIN.

No Committee has been formed, but the Government has promised to contribute, and Señor Riano has been specially appointed to make the necessary arrangements.

UNITED STATES.

The Government has, through Mr. Fish, replied that it is in communication with the various Departments and Scientific Institutions with the object of forwarding the Exhibition.

When men of this position in all branches of Science have given their adhesion to the programme of such an exhibition, its success might well be considered as secured. But these gentlemen did not rest satisfied with merely giving their names in recognition of its value: they have spared no time and labour in making the undertaking a real success. And the Lords of the Committee of Council on Education feel assured that, in offering them their thanks for their invaluable services, they convey not only their own sentiments but the grateful recognition of their labours by the country at large.

It will be readily understood from what has been said of the nature, scope, and method of the exhibition, that a large staff was required, in addition to the permanent staff of the Museum, to organise and arrange the collection in the limited time which could be afforded for that purpose. Special arrangements had, therefore, to be made; and their Lordships have great satisfaction in recording the names of those gentlemen who have rendered very valuable services,—many of them as volunteers—greatly aiding the staff of the Museum in their laborious duties. These were Captain Abney, R.E.; Dr. Atkinson; Mr. Bartlett; Dr. Brunton; Dr. Biedermann; Professor Crum-Brown; Captain Fellowes, R.E.; Professor Carey-Foster; Dr. Michael Foster; Herr Kirchner; Professor Goodeve; Dr. Guthrie; Commander

T. A. Hull, R.N.; Mr. Iselin; Mr. Judd; Mr. Norman Lockyer; Dr. R. J. Mann; Mr. Clements Markham; Professor H. McLeod; Professor Roscoe; Professor Shelley; Dr. Burdon Sanderson; Dr. Schuster; Dr. Voit; and Mr. R. Wylde.

To those men of science who, in this matter and in the work of the general Committee and Sub-Committees, have given much valuable time, and have afforded them the benefit of their great knowledge and experience, the Lords of the Committee of Council on Education feel their best thanks are due, and they trust that the immediate success and future results of the Exhibition, which owes so much to them, will reward them for the labours which they have ungrudgingly devoted to it.

In order to make the Exhibition as useful and interesting as possible, a handbook containing introductory notices to the several sections has been prepared. For writing these notices the Lords of the Committee of Council on Education have been fortunate in securing the services of gentlemen the mention of whose names will be a sufficient indication of the character of the work. These gentlemen are

Captain W. de W. Abney, R.E.
Professor W. Kingdon Clifford, M.A., F.R.S.
Captain J. E. Davis.
Professor G. Carey Foster, B.A., F.R.S.
Professor Geikie, F.R.S.
Professor Goodeve, M.A.
Professor Guthrie, F.R.S.
Professor T. H. Huxley, LL.D., Sec. R.S.
Mr. J. Norman Lockyer, F.R.S.
Professor McLeod.
Mr. Clements R. Markham, C.B., F.R.S.
Mr. N. Story Maskelyne, M.A., F.R.S.
Professor J. Clerk Maxwell, M.A., F.R.S.
Mr. R. H. Scott, M.A., F.R.S.
Professor H. J. S. Smith, M.A., F.R.S.
Mr. W. Warington Smyth, M.A., F.R.S.
Mr. H. C. Sorby, F.R.S.
Mr. W. Spottiswoode, M.A., F.R.S.
Dr. W. H. Stone.
Professor P. G. Tait, M.A.

It had been originally proposed to exhibit the collection of Scientific Apparatus in the South Kensington Museum; but

various circumstances, which could not be foreseen, having rendered it necessary to abandon this intention, Her Majesty's Commissioners for the Exhibition of 1851 most liberally placed the galleries on the western side of the Horticultural Gardens at the disposal of the Science and Art Department for the purpose of the exhibition. Though, unfortunately, these galleries are disconnected from the Kensington Museum, they are admirably adapted to the present purpose, and afford an accommodation which could not otherwise have been obtained.

(By order)

F. R. SANDFORD,

Secretary, Committee of Council on Education.

CLASSIFICATION OF THE COLLECTION.

ARITHMETIC.

Apparatus for teaching arithmetic.—Calculating machines.—Instruments for solving equations.—Slide rules.—Numbering and enumerating apparatus, &c.

GEOMETRY.

Instruments used in geometrical drawing.—Methods of copying.—Pantigraph, micrograph.—Peaucellier's cell and parallel motion.—Machines for description of curves and specimens of the curves they describe, including geometric turning.—Instruments for giving graphic representations of phenomena.—Models to illustrate descriptive geometry.—Specimens to illustrate the process of making models according to a design.—Models to illustrate solid geometry, perspective, crystallography, &c.—Stereoscopic illustrations of solid geometry.

MEASUREMENT.

Of length.—Standard yard, metre, &c.—Comparator for standards of length (sight and touch).—Gauges, measuring wheels, steel tapes, &c.—Micrometers and verniers.—Cathetometers.

Of area.—Planimeters, &c.

Of volume.—Standard gallon, litre, &c.—Pipettes, burettes.—Meters for gas, water, &c.

Of angles.—Divided circles, theodolites, clinometers, goniometers, &c.

Of mass.—Standard pound, kilogramme, &c.—Vacuum and other balances.

Of density.—Specific gravity bottles, areometers, &c.

Of time.—Clocks and pendulums, chronometers, watches, and balance wheels.—Tuning forks for measuring small intervals of time.—Chronographs.

Of velocity.—Such as Morin's machine.—Strophometers, current meters, ships' logs, &c.

Of momentum.—Ballistic apparatus.

Of force.—Spring balances, pressure gauges, torsion balances, &c.

Of work.—Indicators, dynamometers, &c.

KINEMATICS, STATICS, AND DYNAMICS.

Elementary Illustrations.—Position and displacement of a point, a rigid body or a material system.—Composition and resolution of displacements.—Velocity and acceleration, their composition and resolution.—Displacements of a connected system.—Principles of mechanism.—Rolling contact, sliding contact, belting, link connections, shafting, universal joints, &c.—Transmission of work.—Relation between the displacement of two pieces of a machine and the forces which they transmit.—The mechanical powers.—Instruments for illustrating the laws of motion, such as pendulums, gyroscopes, dynamical tops.

Laws of fluid pressure ; stability of floating bodies.

Discharge of fluids through orifices, and their motion in channels.

Hydraulic and pneumatic transmission of power.

MOLECULAR PHYSICS.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Pressure on Matter.—Tension, compression (piezometer), torsion, flexion ; relation of volume to pressure ; elasticity of liquids and gases.—Hardness (of solids and liquids), toughness, brittleness, malleability, &c.

Communication of Pressure through Fluids.—Pressure of air, its consequences and applications.—Barometers, air-pumps, siphons, suction-pumps, spirators, &c. ; Pressure of water, its consequences and applications.—Levels, side pressure, &c.

Density.—Methods of measuring densities of gases, vapours, liquids, solids.

Adhesion and Cohesion.—Condensation of gases in solids, solution of gases in liquids, mixing of gases with gases (diffusion, transpiration, &c.), absorption of liquids by solids (capillarity, &c.), absorption of liquids by gases (evaporation, &c.), mixing of liquids with liquids (Osmose, Diffusion Dialysis).—Evaporation of solids, solution of solids, mixture of solids with solids (cementation, &c.).

SOUND.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Geometrical, Mechanical, and Optical methods of Illustrating the Laws of Wave-Motion.—Progressive waves, composition of vibrations, interference, stationary waves.

Generation of Sound.—Fog-horn, &c.

Conduction of Sound.—Through solids, liquids, and gases, stethoscopes.

Velocity of Sound.

Detection of Sound.—Sensitive flame, &c.

Reflection and Refraction.—Ear trumpets, acoustic lenses, &c.

Dispersion and Absorption.

Musical Sounds.—Pitch, standards of pitch, standard tuning forks, &c. ; methods of measuring and comparing rates of vibration ; toothed wheels,

Syrens, &c.; vibration microscopes, &c.; methods of illustrating the nature of musical intervals; manometric flames, mirrored tuning forks, &c.

Musical Quality.—Illustrations of the different quality of the sounds of various instruments, harmonics, and overtones, resultant tones, instruments for studying quality, resonators, phonautographs, &c.

Musical Instruments Illustrating the above.—Methods of exhibiting the mode of vibration of various instruments and the quality of the sounds yielded by them.

LIGHT.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Production.—Combustion, electric discharge, &c.

Measurement of intensity, velocity.

Action of Matter on Light.—Reflexion, refraction, dispersion, achromatism, direct vision prisms, polarisation, absorption (colour), fluorescence, &c.

Action of Light on Light.—Interference, diffraction, measurement of wave length (optical banks), &c.

Action of Light on Matter.—Photography, radiometry, phosphorescence, &c.

Technical Applications of Optical Principles.—Lighthouse.—Illumination, &c.

HEAT.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Sources of Heat.—Chemical, electrical, dynamical, solar, calorescence, &c.

Effects of Heat on Matter.—Changes of temperature, expansion and change of elasticity, liquefaction, vaporization, &c.

Measurement of Temperature.—Thermometers, pyrometers, &c.

Propagation of Heat.—Radiant heat,—Radiometer, reflection, refraction, radiation, absorption, polarization; Conduction,—Solids, liquids, gases; Convection,—Ventilation, &c.

Effect of change of Molecular State on Temperature.—Freezing mixtures, ice machines, &c.

Effect of change of Pressure and Volume.

Heat Quantity.—Unit of heat, calorimeters, specific heat, &c.—Methods of determining latent heat.

Mechanical Equivalent of Heat—Methods of determining.—Illustrations of thermodynamics.

Electrical Equivalent of Heat.—Methods of determining.

Analysis of Solar Radiation.

MAGNETISM.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Natural Magnets.
Permanent Artificial Magnets.
Electro-Magnets.
Methods of Magnetization.—Effects of Magnetization. Conditions affecting intensity of Magnetization:—Temperature (chemical), composition, strains, &c.
Magnetic Induction of all Substances.—Diamagnetism.
Measurement of intensity of magnetization, magnetic moment.
Terrestrial Magnetism.—Instruments for observation and automatic registration of the magnetic elements.

ELECTRICITY.

Instruments and apparatus employed in teaching, and in the investigations and observations connected with :—

Production and Maintenance of Difference of Potential.—Electrical machines acting by friction, induction (doublers, replenishers, &c., Holz's and Töppler's machines, &c.); galvanic batteries; thermo-electric piles; magneto-electric machines.—Other sources, such as pyro-electricity, pressure electricity, cleavage, capillarity, osmose, &c.

Detection and Measurement of Difference of Potential.—Electroscopes, electrometers, standards of electro-motive force, methods of comparison.

Accumulation of Electricity.—Insulators, condensers, accumulators, effects due to accumulated electricity, distribution on conductors, polarisation of dielectrics, &c.

Measurement and Electric Quantity.—Torsion balances, standard accumulators, methods of comparing electric capacities and dielectric coefficients.

Detection of Measurement of Electric Currents.—Galvanoscopes, galvanometers, voltameters, electro-dynamometers, &c.

Resistance.—Standards of resistance, methods of comparing resistances, methods of establishing absolute standards (British Association unit appar.).

Effects of Electric Currents.—Production of light, heat, electrolysis, electro-diffusion.—Action on magnets, soft iron (electro-magnets), action of currents on currents.

Technical Application of Electricity.—Electric telegraph, &c.

ASTRONOMY.

Star maps, catalogues, globes, orreries, &c.
Meridian instruments.
Arrangements for communicating true time,
Altazimuths, zenith-sectors, sextants, &c.
Equatoreal telescopes { reflectors. refractors.

Micrometers.
Driving clocks.
Special arrangements for—
Celestial photography.
Spectroscopic observations.
Thermo-electric observations.
Siderostats.

APPLIED MECHANICS.

As the Exhibition must be regarded as chiefly referring to education, research, and other scientific purposes, it must in this division consist principally of models, diagrams, mechanical drawings, and small machines, illustrative of the principles and progress of mechanical science, and of the application of mechanics to the arts.

Properties of Materials.
Structures at rest and in motion.
Prime movers.
Reservoirs of energy.
Regulators.
The application of the principles of mechanics to machinery as used in the arts.
Shipping, naval architecture, and marine engineering.

CHEMISTRY.

Scientific instruments, apparatus, and materials employed in the investigation and teaching of chemical science, and in the application of its principles to scientific purposes.

Diagrams and models.
Illustrations of analytical results.
Specimens of chemicals,—(*a*), organic, (*b*) mineral.
Apparatus and fittings for laboratory and lectures.
Apparatus for gravimetric and volumetric operations.
Apparatus for distillation and filtration.
Apparatus for operations by the dry or hot method, such as furnace, blowpipe, &c.
Refrigeratory apparatus.
Apparatus for spectrum analysis.

NOTE.—Operations of the following nature may be illustrated, viz. :—

Organic analysis.
Mineral analysis.
Electrolysis.
Water analysis.
Gas analysis.
Spectrum analysis.
Methods of investigation connected with vegetation and respiration.

METEOROLOGY.

Thermometers and barometers, of special construction.
Anemometers, rain gauges, hydrometers, &c.
Self-recording meteorological apparatus.
Illustrations of various systems of storm signals.
Weather maps.
Instruments illustrating the phenomena of atmospheric electricity.
Instrument stands.

GEOGRAPHY.

Instruments used in surveying.

Instruments used in geodesy and hydrography, including hypsometrical instruments, tide gauges, &c.

Projections, maps, charts, models, and globes.

Deep-sea sounding apparatus.—Seismographical instruments.

GEOLOGY AND MINING.

Instruments for field and underground surveying.

Typical collections of rock specimens, including vein stones.

Typical fossils arranged stratigraphically.

Maps in different stages, and finished maps.

Geological models, horizontal and vertical sections.

Diagrams and plates of fossils, and general geological diagrams used in lecture rooms.

Microscopic sections of rocks and minerals, and apparatus for cutting such sections.

Anemometers, water gauges, mining barometers, and thermometers.

Mining plans, sections and models of workings.

MINERALOGY, CRYSTALLOGRAPHY, ETC.

Goniometers.

Apparatus for studying and exhibiting the optical characters of crystals.

Sections for optical examination.

Blowpipe and other portable apparatus for determining minerals.

Collections of crystals, models of crystals, plates of crystals, and apparatus for drawing them.

Educational collections of minerals, &c.

Diagrams and models for lecture rooms.

BIOLOGY.

1. Microscopes with accessory apparatus for biological research, &c.
2. Physiological apparatus for investigating—
   - *a.* The growth and mechanical movements of living organisms and their parts.
   - *b.* The chemical phenomena of living organisms.
   - *c.* The electrical phenomena of living organisms.
   - *d.* The functions of the nervous and other systems.
3. Apparatus for anatomical research.
4. Apparatus for collecting and preserving objects of natural history.
5. Appliances for teaching biology.

A limited number of examples illustrating the performances of the apparatus will be admissible.

SUB-COMMITTEES OF SECTIONS.

Section I.—Mechanics, including Pure and Applied Mathematics and Mechanical Drawing.

Professor J. C. Adams, M.A., F.RS.
Mr. J. Anderson, LL.D., C.E.
Professor R. Stawell Ball, LL.D., F.R.S.
Rev. A. Barry, D.D.
Mr. W. B. Baskcomb.
Mr. Hugh Birley, M.P.
Major Bolton.
Professor F. A. Bradley.
Mr. F. J. Bramwell, F.R.S.
Mr. T. Brassey, M.P.
Mr. H. W. Chisholm, Warden of the Standards.
Mr. G. T. Clark.
Mr. Latimer Clark.
Professor R. B. Clifton, M.A., F.R.S.
Sir Henry Cole, K.C.B.
Mr. G. Dixon, M.P.
Major-General F. Eardley-Wilmot, R.A., F.R.S.
Mr. D. Glasgow.
Professor T. M. Goodeve, M.A.
The Right Hon. Lord Hampton, G.C.B., F.R.S., President of the Institute of Naval Architects.
Mr. T. E. Harrison, President of the Institute of Civil Engineers.
Sir J. Hawkshaw, F.R.S.
Mr. T. Hawksley, President of the Institute of Mechanical Engineers.
Mr. J. Hick, M.P.
Professor J. C. Maxwell, M.A., F.R.S.
Mr. C. W. Merrifield, F.R.S.
Mr. A. J. Mundella, M.P.
Dr. Pole, F.R.S.
The Right Hon. Lord Rayleigh, F.R.S.
Mr. J. Scott Russell, F.R.S.
Major Seddon, R.E.
Professor Shelley.
Mr. C. W. Siemens, D.C.L., F.R.S.
Professor H. J. S. Smith, M.A., F.R.S.
Mr. G. R. Stephenson.
Professor P. G. Tait, M.A.
Mr. J. Torr, M.P.
Rev. J. F. Twisden, M.A.
Professor W. C. Unwin, B.Sc.
Sir C. Wheatstone, F.R.S. (since deceased).
Sir J. Whitworth, Bart., F.R.S.
Mr. Bennet Woodcroft, F.R.S.
Dr. J. Woolley.
Colonel H. Stuart Wortley.

Section II.—Physics.

Capt. W. de W. Abney, R.E.
Professor W. G. Adams, M.A., F.R.S.
Sir G. B. Airy, K.C.B., D.C.L., F.R.S., Astronomer Royal.
Professor E. Atkinson, Ph. D.
Professor R. Stawell Ball, LL.D., F.R.S.
Professor W. F. Barrett.
Mr. C. O. F. Cator.
Mr. W. Chappell.
Professor R. B. Clifton, M.A., F.R.S.
Vice-Admiral Sir R. Collinson, K.C.B., Deputy Master of the Trinity House.
Dr. Debus, F.R.S.
Mr. Warren De La Rue, D.C.L., F.R.S.
Mr. H. S. Eaton, President of the Meteorological Society.
Professor G. Carey Foster, B.A., F.R.S., President of the Physical Society.
Dr. J. H. Gladstone, F.R.S.

Professor Guthrie, Ph.D., F.R.S.
Mr. J. Baillie-Hamilton.
Mr. J. Hopkinson, B.A., D. Sc.
Mr. W. Huggins, D.C.L., F.R.S., President of the Royal Astronomical Society.
Lord Lindsay, M.P.
Mr. J. Norman Lockyer, F.R.S.
Reverend R. Main, M.A., F.R.S.
Dr. R. J. Mann.
Mr. C. W. Merrifield, F.R.S.
Dr. Pole, F.R.S.
The Right Hon. Lord Rayleigh, F.R.S.
Professor A. W. Reinold, M.A.
Earl of Rosse, D.C.L., F.R.S.
Mr. R. H. Scott, M.A., F.R.S.
Mr. W. Spottiswoode, M.A., F.R.S.
Dr. W. H. Stone.
Lieut.-Colonel Strange, F.R.S.
Professor P. G. Tait, M.A.
Professor Tyndall, LL.D., F.R.S.
Mr. C. V. Walker, F.R.S., President of Society of Telegraphic Engineers.
Sir C. Wheatstone, F.R.S. (since deceased).
Dr. Woolley.

SECTION III.—CHEMISTRY.

Professor F. A. Abel, F.R.S., Chemist to the War Department.
Professor Bloxam.
Sir Henry Cole, K.C.B.
Mr. Warren De La Rue, D.C.L., F.R.S.
Professor Frankland, Ph.D., D.C.L., F.R.S.
Dr. Gilbert, F.R.S.
Dr. J. H. Gladstone, F.R.S.
Professor Odling, M.A., F.R.S., President of the Chemical Society.
Dr. Percy, F.R.S.
Mr. J. A. Phillips.
The Right Hon. Lyon Playfair, Ph.D., C.B., M.P., F.R.S.
Professor Roscoe, Ph.D., F.R.S.
Dr. W. J. Russell, F.R.S.
Professor Williamson, Ph.D., F.R.S.

SECTION IV.—PHYSICAL GEOGRAPHY, GEOLOGY, AND MINERALOGY.

Mr. D. T. Ansted, M.A., F.R.S.
Mr. H. Bauerman.
Professor F. A. Bradley.
Mr. H. W. Bristow, F.R.S.
Major-General Cameron, C.B., F.R.S.
Vice-Admiral Sir R. Collinson, K.C.B., Deputy Master of the Trinity House.
Professor P. M. Duncan, M.B., F.R.S., President of the Geological Society.
Sir P. De M. G. Egerton, Bart., M. P F.R.S.
Mr. R. Etheridge, F.R.S.
Captain Evans, R.N., C.B., F.R.S. Hydrographer of the Navy.
Mr. J. Evans, F.R.S.
Mr. D. Forbes, F.R.S.
Professor Hughes.
Lieut.-General Sir H. James, R.E., F.R.S.
Mr. N. Story-Maskelyne, M.A., F.R.S.
Mr. C. W. Merrifield, F.R.S.
Professor Miller, M.A., LL.D., F.R.S.
Professor Morris.
Professor Prestwich, F.R.S.
Professor A. C. Ramsay, LL.D., F.R.S.
Major-General Sir H. C. Rawlinson, K.C.B., F.R.S., President of the Royal Geographical Society.
Mr. W. Warington Smyth, M.A., F.R.S.

Mr. H. C. Sorby, F.R.S., President of the Royal Microscopical Society.

Major-General R. Strachey, C.S.I. F.R.S,

SECTION V.—BIOLOGY.

The Right Hon. Lord Aberdare, President of the Royal Horticultural Society.

Professor H. W. Acland, M.D., F.R.S., President of the Medical Council of the United Kingdom.

Dr. G. J. Allman, F.R.S., President of the Linnæan Society.

Mr. G. Bentham, F.R.S.

Mr. C. Brooke, M.A., F.R.S.

Mr. G. Busk, F.R.S.

Dr. W. B. Carpenter, C.B., F.R.S.

Professor W. T. Thiselton Dyer, M.A., B.Sc.

Professor Flower, F.R.S.

Professor Michael Foster, M.D., F.R.S.

Colonel Lane Fox, President of the Anthropological Institute.

Mr. A. H. Garrod, M.A.

Mr. A. C. L. G. Günther, M.A., M.D., F.R.S.

The Hon. Alan Herbert.

Dr. J. D. Hooker, C.B., President of the Royal Society.

Professor T. H. Huxley, LL.D., F.R.S.

Professor E. Ray Lankester, M.A., F.R.S.

Mr. W. K. Parker, F.R.S.

Mr. G. W. Royston-Pigott, M.A., M D., F.R.S.

Professor W. Rutherford, M.D.

Professor J. S. Burdon Sanderson, M.D., F.R.S.

Mr. H. C. Sorby, F.R.S., President of the Royal Microscopical Society.

Mr. F. H. Wenham.

GENERAL CONSIDERATIONS

CONCERNING

SCIENTIFIC APPARATUS.

I.—Experiments.

The aim of Physical Science is to observe and interpret natural phenomena.

Of natural phenomena, some—as, for example, those of astronomy—are not subject to our control, and in the study of these we can make use only of the method of Observation. When, however, we can cause the phenomenon to be repeated under various conditions, we are in possession of a much more powerful method of investigation—that of Experiment.

An Experiment, like every other event which takes place, is a natural phenomenon; but in a Scientific Experiment the circumstances are so arranged that the relations between a particular set of phenomena may be studied to the best advantage.

In designing an Experiment the agents and phenomena to be studied are marked off from all others and regarded as the Field of Investigation. All agents and phenomena not included within this field are called Disturbing Agents, and their effects Disturbances; and the experiment must be so arranged that the effects of these disturbing agents on the phenomena to be investigated shall be as small as possible.

We may afterwards change the field of our investigation, and include within it those phenomena which in our former investiga-

tion we regarded as disturbances. The experiments must now be designed so as to bring into prominence the phenomena which we formerly tried to get rid of. When we have in this way ascertained the laws of the disturbances, we shall be better prepared to make a more thorough investigation of what we began by regarding as the principal phenomena.

Thus, in experiments where we endeavour to detect or to measure a force by observing the motion which it produces in a movable body, we regard Friction as a disturbing agent, and we arrange the experiment so that the motion to be observed may be impeded as little as possible by friction.

2.—Apparatus.

Everything which is required in order to make an experiment is called Apparatus.

A piece of apparatus constructed specially for the performance of experiments is called an Instrument.

Apparatus may be designed to produce and exhibit a particular phenomenon, to eliminate the effects of disturbing agents, to regulate the physical conditions of the phenomenon, or to measure the magnitude of the phenomenon itself.

In many experiments, special apparatus is required for all these purposes, but certain pieces of apparatus are used in a great variety of experiments, and there are whole classes of instruments which have certain principles of construction in common.

Thus, in all instruments in which motion is to be produced there must be a prime mover or driving power, and a train of mechanism to connect the prime mover with the body to be moved; and in many cases additional apparatus is necessary—such as a break to destroy the superfluous energy of the prime mover, or a reservoir to store up its energy when not required; and we may have special apparatus to measure the force transmitted, the velocity produced, or the work done, or to regulate them by automatic governors.

We may make a somewhat similar classification of the functions of apparatus belonging to other physical sciences—such as Electricity, Heat, Light, Sound, &c.

3.—General Principle of the Construction of Apparatus.

There are certain primary requisites, however, which are common to all instruments, and which therefore are to be carefully considered in designing or selecting them. The fundamental principle is, that the construction of the instrument should be adapted to the use that is to be made of it, and in particular, that the parts intended to be fixed should not be liable to become displaced; that those which ought to be movable should not stick fast; that parts which have to be observed should not be covered up or kept in the dark; and that pieces intended to have a definite form should not be disfigured by warping, straining, or wearing.

It is therefore desirable, before we enter on the classification of instruments according to the phenomena with which they are connected, to point out a few of the principles which must be attended to in all instruments.

Each solid piece of an instrument is intended to be either fixed or movable, and to have a certain definite shape. It is acted on by its own weight, and other forces, but it ought not to be subjected to unnecessary stresses, for these not only diminish its strength, but (what for scientific purposes may be much more injurious) they alter its figure, and may, by their unexpected changes during the course of an experiment, produce disturbance or confusion in the observations we have to make.

We have, therefore, to consider the methods of relieving the pieces of an instrument from unnecessary strain, of securing for the fixed parts a determinate position, and of ensuring that the movable parts shall move freely, yet without shake.

This we may do by attending to the well-known fact in kinematics—"A Rigid Body has Six Degrees of Freedom."

A rigid body is one whose form does not vary. The pieces of

our instruments are solid, but not rigid. They are liable to change of form under stress, but such change of form is not desirable, except in certain special parts, such as springs.

Hence, if a solid piece is constrained in more than six ways it will be subject to internal stress, and will become strained or distorted, and this in a manner which, without the most exact micrometrical measurements, it would be impossible to specify.

In instruments which are exposed to rough usage it may sometimes be advisable to secure a piece from becoming loose, even at the risk of straining and jamming it; but in apparatus for accurate work it is essential that the bearings of every piece should be properly defined, both in number and in position.

4.—Methods of placing an Instrument in a Definite Position.

When an instrument is intended to stand in a definite position on a fixed base it must have six bearings, so arranged that if one of the bearings were removed the direction in which the corresponding point of the instrument would be left free to move by the other bearings must be as nearly as possible normal to the tangent plane at the bearing.

(This condition implies that, of the normals to the tangent planes at the bearings, no two coincide; no three are in one plane, and either meet in a point or are parallel; no four are in one plane, or meet in a point, or are parallel, or, more generally, belong to the same system of generators of an hyperboloid of one sheet. The conditions for five normals and for six are more complicated.)*

These conditions are satisfied by the well-known method of forming on the fixed base three **V** grooves, whose sides are inclined 45° to the base, and whose directions meet in a point at angles of 120°. The instrument has three feet; the end of each foot is, roughly speaking, conical, but so rounded off that it bears

* See Ball on the Theory of Screws.

against the two sides of the groove, and cannot reach the bottom. The instrument has thus six solid bearings, and is kept in its place by its weight, without being subjected to any unnecessary strain.

Sir William Thomson, who has bestowed much attention on this subject, has adopted a somewhat different arrangement in some of his instruments. A triangular hole, like that formed by pressing an angle of a cube into a mass of clay, is formed in the base, and a **V** groove is cut in a direction passing through the centre of the hole. The three feet of the instrument are all rounded, but of different lengths. The longest stands in the triangular hole, and has three bearings; the second stands in the **V** groove, and has two bearings; and the third stands on the horizontal plane of the base, and has one bearing. There are thus six bearings in all. This method, though it does not give so large a margin of stability as the method of three grooves, has this advantage, that as each of the three feet is differently formed, it is impossible to put any but the proper foot into the hole without detecting the mistake.

5.—Bearings of Mirrors.

In mounting mirrors it is especially important to attend to the number and position of their bearings, for any stress on the mirror spoils its figure, and renders it useless for accurate work.

For small mirrors it is best to make one face of the mirror rest against three solid bearings, and to keep it in contact with these by three spring bearings placed exactly opposite to them against the other face of the mirror. These will prevent any displacement of the mirror out of its proper plane. The bearings against the edges of the mirror, by which it is prevented from shifting in its own plane, are, in the case of small mirrors, of less importance.

When the mirror is large, as in the case of the speculum of a large telescope, a greater number of bearings is required to prevent the

mirror from becoming strained by its own weight; but in all cases the number of *fixed* bearings at the back of the mirror must be three and only three, otherwise any warping of the framework will entirely spoil the figure of the surface.

6.—Bearings of Standards of Length.

It is of the greatest importance that the standard measure of length, by which the national unit of length is defined, should not be exposed to strain.

The box in which the standard yard is kept in the Exchequer Chamber is provided with bearings, the positions of which have been arranged so that the bar may rest on them with as little strain throughout its substance as is consistent with the fact that it is a heavy body.

7.—On the Bearings of Movable Parts.

The most important kinds of motion with one degree of freedom are, (1) Rotation round an axis; (2) Motion of translation without rotation; and (3) Screw motion, in which a definite rotation about an axis corresponds to a definite motion of translation along that axis.

For one degree of freedom five solid bearings are required, the sixth condition being supplied by that part of the instrument which regulates the motion of the piece.

The construction of pieces capable of rotation about an axis is better understood than any other department of mechanism.

In astronomical instruments, four of the bearings are supplied by the two **Y**'s on which the cylindrical end-pieces of the axle rest, and the fifth by the longitudinal pressure of a bearing against one end of the axle, or a shoulder formed upon it. The weight of the instrument is generally sufficient to keep it in contact with its bearings; but when the weight is so great that the pressure on the bearings is likely to injure them, the greater part of the weight is supported by auxiliary bearings, the pressure

of which is regulated by counterpoises or springs, leaving only a moderate pressure to be borne by the true bearings.

8.—Translation.

Motion of translation in a fixed direction, without rotation.

This kind of motion is required for pieces which slide along straight fixed pieces, as the verniers and microscopes of measuring apparatus, such as cathetometers and micrometers, the slide-rests of lathes, the pistons of steam engines and pumps, &c.

When a tripod stand is to have a motion of this kind in a horizontal plane, two of its feet may be made to slide in a **V** groove, while the third rests on the horizontal plane.

When a cylindrical rod is to have a longitudinal motion, it must be made to bear against two fixed **Y**'s, and must be prevented from rotating on its axis by a bearing, connected either with the cylinder or the fixed piece, which slides on a surface whose plane passes through the axis of the cylinder.

When, as in cathetometers and other measuring apparatus, a piece has to slide along a bar, the five bearings of the piece may be arranged so that three of them form a triangle on one face of the bar, while the two others rest against an adjacent face of the bar, the line joining these two being in the direction of motion. These bearings may be kept tight, without the possibility of jamming, by means of spring bearings against the other sides of the bar.

9.—Parallel Motion by Linkwork.

In all these methods of guiding a piece by sliding contact, there is a considerable waste of energy by friction. In many cases, however, this is of little moment, compared with the errors depending on the necessary imperfection of the guiding surfaces, arising not only from original defects of workmanship but from straining and wearing during use.

It is true that great advances have been made, and notably by Sir J. Whitworth, in the art of forming truly plane and cylindric

surfaces; but even these are liable to become altered, not only by wear but by strain and by inequalities of temperature, so that it is never safe to depend upon the perfect accuracy of the fitting of a large bearing surface, except when the pressure is very great.

In linkwork, on the other hand, the relative motion of any two pieces at their mutual bearing is one of pure rotation about a well-turned axle. The extent of the sliding surfaces is thus reduced to a minimum, so that less power is lost by friction, and the workmanship of such bearings can be brought much nearer to perfection than that of any other kind of fittings. Hence, in all prime movers and other machines, in which waste of power by friction is to be avoided, and even in those in which great accuracy is required, it is desirable, if it is possible, to guide the motion by linkwork.

The so-called "Parallel Motion" invented by James Watt was the first attempt to guide a motion of translation by means of linkwork; but though the motion as thus guided is very nearly rectilinear, it is not exactly so. Various other contrivances have been invented since the time of Watt, as, for instance, that fitted to the engines of the *Gorgon* by Mr. Seaward; but all of them involved either a deviation from true rectilinear motion, or a sliding contact on a plane surface, and it was generally supposed by mathematicians that a true rectilinear motion, guided by pure linkwork, was a geometrical impossibility.

It was in the year 1864 that M. Peaucellier published his invention of an exact parallel motion by pure linkwork, and thus opened up the path to a very great extension of the science of mechanism, and its practical applications. The linkwork motions constructed by M. Garcia, Mr. Penrose, and others, and the extensions of the theory of linkwork by Sylvester, Hart, and Kempe, are now well known, but they could not be fully described within our present limits.

10.—Screw Motion.

The adjustments of instruments are to a great extent made by means of screws. In the case of levelling screws, which bear the weight of an instrument, the thread of the screw is always in contact with its proper bearing in the nut; but in micrometer screws it is necessary to secure this contact by means of a spring. This spring is sometimes made to bear against the end of the screw, or a shoulder turned upon it; but this arrangement causes a variable pressure as the screw moves forward. A much better arrangement is to make the spring bear, not against the screw itself, but against a nut which is free to move on the screw, but which is prevented from turning round by a proper bearing. This movable nut always remains at the same distance from the fixed one, so that the pressure of the spring remains constant. This is the arrangement of the micrometer screws in Sir W. Thomson's electrometers.

11.—On Contrivances for securing Freedom of Motion.

In many instruments there is a movable part or indicator, the position or motion of which is to be observed in order to deduce therefrom some conclusion with respect to the force which acts upon it. This force may be the weight of a body, or an attractive or repulsive force of any kind; but, besides the force we are investigating, the resistance called Friction is always acting as a disturbing force.

If the magnitude and direction of the force of friction were at all times accurately known, this would be of less consequence; but the amount of friction is liable to sudden alterations, owing to causes which we can often neither suspect nor detect, so that the only way in which we can make any approach to accuracy is by diminishing as much as possible the effect of friction. The modes by which this is effected are of two kinds. Whenever there is sliding contact, there is friction; and wherever there is complete freedom of motion there must be sliding contact; but by making

the extent of the sliding motion small compared with the motion of the indicating part, we may reduce the effect of friction to a very small part of the whole effect.

This is done in rotating parts by diminishing the size of the axle, and by supporting it on friction-wheels; and in toothed wheels by keeping the bearings of the teeth as near as possible to the line of centres, or more perfectly by cutting the teeth obliquely, as in Hooke's teeth.* A compass needle is balanced on a fine point, and the extent of the bearing is so small that a very small force applied to either end of the needle is sufficient to turn it round.

In all these instances the effect of friction is reduced by diminishing the extent of the sliding motion.

In balances and other levers the bearing of the lever is in the form of a prism, called a knife-edge, having an angle of about 120°; the edge of this prism is accurately ground to a straight line, and rests on a plane horizontal surface of agate.

The relative motion in this case is one of rolling contact.

In another class of instruments sliding and rolling are entirely done away with, and sufficient freedom of motion is secured by the pliability of certain solid parts.

Thus many pendulums are hung, not on knife-edges, but on pieces of watch-spring, and torsion balances are suspended by metallic wires or by silk fibres. The motion of the piece is then affected by the elastic force of the suspension apparatus, but this force is much more regular in its action than friction, and its effects can be accurately taken account of, and a proper correction applied to the observed result.

12.—The Torsion Rod, or Balance of Torsion.

The balance of torsion has been of the greatest benefit to modern science in the measurement of small forces. The first

* Communicated to the Royal Society in 1666. See Willis's Principles of Mechanism, 1870, p. 53.

instrument of the kind was that constructed by the Rev. John Michell, formerly Woodwardian Professor of Geology at Cambridge, in order to observe the effect of the attraction of a pair of large lead balls on a pair of smaller balls hung from the extremities of the rod of the balance. Michell, however, died before he had opportunity to make the experiment, and his apparatus came into the hands of Professor F. J. H. Wollaston, and was transmitted by him to Henry Cavendish. Cavendish greatly improved the apparatus,* and successfully measured the attraction of the balls, and thus determined the density of the earth.†

The experiment has since been repeated by Reich and Baily. In the meantime, however, independently of Michell, and before Cavendish had actually used the instrument, Coulomb ‡ had invented a torsion balance, by which he established the laws of the attraction and repulsion of electrified and magnetic bodies.

13.—BIFILAR SUSPENSION.

The elastic force of torsion of a wire, though much more regular than the force of friction, is subject to alterations arising from hitherto unknown causes, but probably depending on facts in the previous history of the wire, such as its having been subjected to twists and other strains before it was hung up. Hence it is sometimes better to employ another mode of suspension, in which the force of restitution depends principally on the weight of the suspended parts.

The body is suspended by two wires or fibres, which are close together and nearly vertical, and are so connected by a pulley that their tensions are equal. The body is in equilibrium when the two fibres are in the same plane. When the body is turned about a vertical axis, the tension of the fibres produces a force tending to turn the body back towards its position of equilibrium ; and this

* Cavendish's apparatus now belongs to the Royal Institution.

† "Philosophical Transactions," 1798.

‡ "Mém. de l' Academie," 1784, &c.

force is very regular in its action, and may be accurately determined by proper experiments.

This arrangement, which is called the Bifilar suspension, was invented by Gauss and Weber for their magnetic apparatus. It was afterwards used by Baily in his experiments on the attraction of balls.

14.—Methods of Reading.

The observed position of the indicating part of an instrument is recorded as the "Reading." To ascertain the position of the indicating part of the instrument various methods have been adopted. The commonest method is to make the indicating part in the form of a light needle, the point of which moves near a graduated circle. The position of the needle is estimated by observing the position of its point with respect to the divisions of the scale. By giving the needle two points at opposite extremities of a diameter, and observing the position of both points, we may eliminate the errors arising from the want of coincidence between the centre of the graduated circle and the axis of motion of the needle.

This is the method adopted in ordinary magnetic compasses: As it is necessary for freedom of motion that the point of the needle should not be in actual contact with the graduated limb, the reading will be affected by any change in the position of the eye of the observer. The error thus introduced is called the error of Parallax. In some instruments, therefore, the observation is made through an eye-hole in a definite position. A better plan, however, is to place a plane mirror under the needle, and in taking the reading to place the eye so that the needle appears to cover its own reflexion in the mirror.

15.—Spiegel-Ablesung, or Mirror-Reading

A still more accurate method is that invented by Poggendorff, and used by Gauss and Weber in their magnetic observations. A small plane mirror is attached to the indicating piece, so as to

turn with it about its axis, which we may suppose vertical. A divided scale is placed so as to be perpendicular to this axis, and so that a normal to the scale at its middle point passes through the axis. The image of this scale by reflexion in the mirror is observed by means of a telescope having a vertical wire in the plane of distinct vision. As the indicating piece turns about its axis, the image of the scale passes across the field of view of the telescope, and the coincidence of the image of any division of the scale with the vertical wire of the telescope may be observed.

The error of parallax is entirely got rid of by this method, for the two optical images whose relative position is observed are in the same plane.

Another method of using the mirror is to reverse the direction of the rays of light by removing the eye-piece of the telescope, and putting the flame of a lamp in its place. The light emerging from the object-glass falls on the mirror, and is reflected so as to form on the scale a somewhat confused image of the flame, with a distinct image of the vertical wire crossing it. The reading is made by observing the position on the scale of the image of the vertical wire. In many instruments the telescope is dispensed with, and the mirror is a concave one, as in Thomson's reflecting galvanometer.

Some German writers distinguish this method of using the mirror and scale with a lamp as the *objective* method, the method in which the observer looks through the telescope being called the *subjective* method. The objective method is the only one adapted for the photographic registration of the readings.

16.—Ramsden's Ghost.

To ascertain the exact position of an instrument with respect to a plumb-line without touching the line, Ramsden fixed a convex lens to a part of his instrument, and placed a wire so that when the instrument was in its proper position the image of the plumb-line formed by the lens exactly coincided with the fixed wire. By

moving the instrument till this coincidence was observed, the instrument was adjusted to its proper position. This contrivance was long known as "Ramsden's Ghost." It is, in fact, a simple form of the reading microscope; and there is no better method of ascertaining that a delicately-suspended object is exactly in its proper place.

17.—Collimating Telescope.

If two telescopes are made to face one another, and if the cross-wires of the first, as seen through the second, appear to coincide with the cross-wires of the second, the optic axes of the two instruments are parallel. This mode of ascertaining parallelism is used in practical astronomy, and is called the method of collimating telescopes, or of collimators.

It is also used in the Kew portable magnetometer. The magnet is hollow, and carries a lens at one end and a scale at the other, at the principal focus of the lens. The magnet is thus a collimating telescope, and is observed by means of a telescope mounted on a divided circle. The disadvantage of this method is, that when the magnet is deflected, the scale soon passes out of the field of view, and the observer has to shift his telescope, in order to get a new reading.

18.—Three Classes of Readings.

We may, in fact, arrange instruments in three classes, according to the method of reading them.

In the self-recording class the observer leaves the instrument to itself, and examines the record at his own convenience.

In those which depend on eye observations alone, the observer must be there to look at the indicator of the instrument, but he does not touch it.

In the third class, which depend on eye and hand, the observer, before taking the reading, must make some adjustment of the instrument.

19.—Functions of Instruments.

The foregoing remarks apply to the constituent parts of instruments, without reference to the special department of science to which they belong.

The classification of special instruments will be best understood if we arrange those belonging to each department of science according to their respective functions; some of these functions having instruments corresponding to them in several departments of science, while others are peculiar to one department.

All the physical sciences relate to the passage of energy, under its various forms, from one body to another; but Optics and Acoustics are often represented as relating to the sensations of sight and hearing. These two sciences, in fact, have a physiological as well as a physical aspect, and therefore some parts of them have less analogy with the purely dynamical sciences.

The most important functions belonging to instruments, or elements of instruments, are as follows:—

1.—The Source of energy. The energy involved in the phenomenon we are studying is not, of course, produced from nothing, but it enters the apparatus at a particular place, which we may call the Source.

2.—The channels or distributors of energy, which carry it to the places where it is required to do work.

3.—The restraints, which prevent it from doing work when it is not required.

4.—The reservoirs in which energy is stored up till it is required.

5.—Apparatus for allowing superfluous energy to escape.

6.—Regulators for equalising the rate at which work is done.

7.—Indicators, or movable pieces, which are acted on by the forces under investigation.

8.—Fixed scales on which the position of the indicator is read off.

Thus in solid machinery we have—

1.—Prime movers.
2.—Trains of mechanism.
3.—Fixed framework.
4.—Fly-wheels, springs, weights raised.
5.—Friction breaks.
6.—Governors, pendulums, balance springs in watches.
7.—Dynamometers, Strophometers, Watt's indicator, chronographs, &c.
8.—Scales for these indicators. Standards of length and mass. Astronomical standard of time.

For the phenomena depending on fluid pressure we have—

1.—Pumps, condensing and rarifying syringes, Örsted's Piezometer, Andrews's apparatus for high pressure.
2.—Pipes and tubes.
3.—Packing, washers, caoutchouc tubes, paraffin joints; fusion and other methods of making joints tight.
4.—Air chambers, water reservoirs, vacuum chambers.
5.—Safety valves.
6.—Governors by Siemens and others, Cavaillé-Col's regulator for organ blast.
7.—Pressure-gauges, barometers, manometers, sphygmographs, &c.; areometers, and specific gravity bottles; current meters, gas meters.
8.—Scales for these gauges.

For thermal phenomena—

1.—Furnaces, blow-pipe flames, freezing mixtures, solar and electric heat.
2.—Hot water pipes, copper conductors.
3.—Non-conducting packing, cements, clothing, &c.; steam-jackets, and ice-jackets.
4.—Regenerators, heaters, &c.

5.—Condensers and safety valves.

6.—Thermostats, (1) by regulation of gas; (2) by boiling a liquid of known composition.

7.—Thermometers. Pyrometers, Thermoelectric Pile, Siemens' resistance thermometer; Calorimeters.

8.—Standard temperatures: as those of melting ice, boiling water, &c.

For electric phenomena—

1.—Electric machines, frictional machine, electrophorus, Holtz' machine; voltaic batteries, thermo-electric batteries, magneto-electric machines.

2.—Wires and other metallic conductors; armatures of magnets.

3.—Insulators.

4.—Leyden jars and other "condensers;" secondary batteries or cells of polarization; magnets, and electro-magnets.

5.—Rheostats, lightning conductors, &c.

6.—Guthrie's voltastat, regulators of electric lamps, &c.

7.—Electroscopes and electrometers, Coulomb's torsion balance, voltameters, galvanometers and electrodynamometers, magnetometers.

8.—Standards of resistance, capacity, electro-motive force, &c., as the Ohm, the microfarad, L. Clark's voltaic constant cell.

From the physical, as distinguished from the physiological point of view, the science of Acoustics relates to the excitement of vibrations and the propagation of waves in solids, liquids, and gases, and that of Optics to the excitement of vibrations, and the propagation of radiation, in the luminiferous medium.

From the physiological point of view, only those waves in ordinary matter are considered which excite in us the sensation of Sound, though waves which do not excite this sensation can be detected and studied by appropriate methods.

In the physiological treatment of Optics, only those radiations are considered which excite in us the sensation of Light, though other radiations can be detected and studied by their thermal, chemical, and even mechanical effects.

VIBRATIONS AND WAVES.

PHYSICAL ASPECT OF ACOUSTICS.

1.—Sources. Vibrations of various bodies.

Air—Organ pipes, resonators and other wind instruments.

Reed instruments.

The Siren.

Strings . . .	Harp, &c.
Membranes . .	Drum, &c.
Plates . . .	Gong, &c.
Rods . . .	Tuning-fork, &c.

2.—Distributors.	Air .	Speaking tubes, stethoscopes, &c.
	Wood,	Sounding rods
	Metal,	Wires.

3.—Pugging of floors, &c.

4.—Reservoirs. Resonators, Organ Pipes, Sounding-boards.

5.—Dampers of pianofortes.

6.—Regulators. Organ Swell.

7.—Detectors, the ear; Sensitive Flames, Membranes, Phonautographs, &c.

8.—Tuning-forks, pitch-pipes, and musical scales.

HEARING.

PHYSIOLOGICAL ASPECT OF ACOUSTICS.

Apparatus for determining the conditions—

1.—Of the audibility of sounds.

2.—Of the perception of the distinction of sounds.

3.—Of the harmony or discord of simultaneous sounds.
4.—Of the melodious succession of sounds.
5.—Of the timbre of sounds, and of the distinction of vowel sounds.
6.—Of the time required for the perception of the sensation of sound.

RADIATION.

PHYSICAL ASPECT OF OPTICS.

1.—Sources of Radiation. Heated bodies, solid, liquid, and gaseous.

Solid.—Heated by a blow-pipe as in the oxy-hydrogen limelight.

Heated by their own combustion, as in the magnesium light and glowing coals.

Heated by an electric current, as the carbon electrodes of the electric lamp.

Heated by concentrated radiation from other sources, as in the phenomenon called Calescence.

Liquid, as in hot fused metals and other bodies.

Gaseous.—Heated by their own combustion, as in flames.

Heated by a Bunsen burner, as the sodium light.

Heated by the voltaic arc.

Heated by the induction spark.

2.—Distributors. Burning mirrors and lenses, condensing lenses for solar microscopes, magic lanterns, &c., lighthouse apparatus; telescopes, microscopes, &c.
3.—Selectors. Absorbing media and coloured bodies in general, prisms and spectroscopes, ruled gratings, &c.: tourmalines, Nicol's prisms, and other polarizers.
4.—Phosphorescent, fluorescent, and calescent bodies.
5.—Opaque screens, diaphragms, and slits.

6.—Regulators. The iris of the eye.

7.—Photometers, photographic apparatus, actinometer, thermopile, Bunsen and Roscoe's photometer, selenium photometer, Crookes' radiometer, and other instruments.

8.—Fraunhofer's lines of reference, and maps of the spectrum. Standard sperm candle, burning 120 grains of sperm per hour.

SIGHT.

PHYSIOLOGICAL ASPECT OF OPTICS.

Apparatus for determining the conditions of—

1.—The visibility of objects, with respect to size, illumination, &c.

2.—The perception of the distinction of objects.

3.—The perception of colour, as depending on the composition of the light coming from the object.

Apparatus for comparing the intensity of luminous impressions, as depending on the intensity of the exciting cause and on the time during which it has acted, and for tracing the course of the development of a luminous impression from its first excitation to its final decay and extinction.

Ophthalmometers, for measuring the dimensions of the eye and determining its motions; and for ascertaining the two limits of distinct vision.

Ophthalmoscopes, for illuminating and observing the interior of the eye.

BIOLOGICAL APPARATUS.

1.—For measuring the ingesta, egesta, and weight of living beings.

2.—For testing the strength of animals and measuring the work done by them.

3.—For measuring the heat which they generate.

4.—For determining the conditions of fatigue of muscles.

5.—For investigating the phenomena of the propagation of impulses through the nerves, and of the excitement of muscular action.

6.—For tracing and registering the rhythmic action of the circulatory and respiratory operations—cardiographs, sphygmographs, stethoscopes, &c.

7.—Marey's apparatus for registering the paces of men, horses, &c., and the actions of birds and insects during flight.

8.—Instruments for illuminating and rendering visible parts within the living body—ophthalmoscopes, laryngoscopes, &c.—and arrangements for transmitting light through parts of the living body.

9.—Instruments for varying the electrical state of the body—induction coils, &c.

10.—Instruments for determining the electric state of living organs—galvanometers with proper electrodes, electrometers, &c.

J. CLERK MAXWELL.

ARITHMETICAL INSTRUMENTS.

Of all those branches of human knowledge which are comprehended under the name of Science, Arithmetic is that which has the most abstract character, and which, at the same time, is of the most universal application in the study of natural phenomena. The art of counting, or of numeration, is one of the earliest, if not the earliest product of nascent civilisation; and, in the case of the savage races of mankind, the greater or less progress which has been made towards the acquisition of this art affords no unfair measure of the degree of culture and of intellectual development which has been attained. It is said that there are races whose scale of numeration is limited to two or three; others can go to five, or ten, or twenty. And we may be sure that no tribe of men, untaught by a superior race, ever acquired the art of counting by hundreds or thousands, without possessing a high average of mental capacity, and without sharing in the privilege, accorded only to certain nations, of occasionally producing men of inventive genius, and real leaders of thought.

The more favoured branches of the Semitic and Aryan families —the Jews, the Egyptians, the Greeks, the Sanskrit-speaking nations of India—must have reached this comparatively speaking advanced standard of culture at a very remote period. But it is remarkable that the real extent of the domain of arithmetic—a domain in a certain sense coequal with that of exact science—was not perceived till a much later epoch.

The Greek philosophers, at least as early as the time of Aristotle,

had learned to distinguish between *discrete*, or *discontinuous*, and *continuous* quantity. All counting, properly so called, is of discontinuous quantity; all measurement is of continuous quantity. To use a simple illustration: if we are counting points or dots on a line, we can say, "two dots and one dot make three dots;" if we are measuring inches we can equally say, "two inches and one inch make three inches." But in the latter case we can, if we please, pass by insensible degrees, and through every intermediate gradation of magnitude, from two inches to three inches: in the former case we can only pass abruptly from counting two dots to counting three dots; there is no such thing as half a dot, and no intermediate stage is conceivable.

But while this important distinction was clearly seen in very ancient times, being indeed of a nature to commend itself specially to the philosophical spirit of classical antiquity, there was not an equally distinct apprehension of the truth that continuous quantity, no less than discontinuous, appertains to the domain of arithmetic. By whom the first dim perception, or by whom the first vivid realisation, of this truth was attained, we have no means of ascertaining with precision. It must have been gradually impressed on the minds of men by the growth of science. It is, perhaps, hardly discernible in the writings of Plato and Aristotle: it underlies, but is carefully excluded from, the fifth book of the Elements of Euclid. It must have been present to the mind of Archimedes when he measured the proportions to one another of the sphere, the cylinder, and the cone; it must have forced itself on the notice of the Greek astronomers, whose business it was to record numerically at discontinuous intervals the phases of continuous phenomena; and it became firmly established as an axiomatic principle by the development of that mode of arithmetic which is called algebra; by the great invention of Descartes which reduced geometry to algebra; and, last of all, by the creation of those arithmetical methods which are briefly described as the infinitesimal calculus.

Although this conception of the absolute continuity of arithmetical magnitude is of a very abstract character, it has exercised a preponderating influence over scientific thought. That, on the one hand, all natural phenomena take place by a continuous process, and that they are all measurable quantitatively: that, on the other hand, the law of any continuous process can be expressed by an arithmetical formula, and the amount of any quantitative measurement can be stated in arithmetical figures, are propositions which are admitted by every one who understands them, and which, indeed, are in some instances believed with a more unlimited faith than is warranted by the evidence, strong as it is, which can be brought in support of them. Nor is this all; for if there be any one opinion concerning nature at the present time universally accepted by scientific men, it is that the minutest as well as the greatest phenomena are subject to a "reign of law." And if we ask for the strongest reasons which can be given for this belief, they may be summed up by saying that, so far as our measurements are exact, and so far as our arithmetic has been able to cope with the arithmetic of nature, we have uniformly found our observations of continuous phenomena to be in strict accordance with our deductions from the abstract science of continuous number.

We proceed to offer a few observations with reference to each of the two branches of arithmetic—that of discontinuous and that of continuous quantity. The course of these remarks will make it clear, why it is that a science of incalculable importance to other sciences, does not, nevertheless, make any considerable display of its pretensions in an exhibition of scientific apparatus.

(1.) The simple operations of counting, and of recording numbers counted, and of comparing them with one another, which constitute the main business of practical arithmetic, have been so facilitated by the two great inventions of the decimal system of notation, and of logarithms, that, in many cases, but little

inducement has existed to supersede the labour involved in such calculations by means of mechanical appliances.

Counting machines, however, for certain purposes have been found indispensably necessary. A clock is defined by Sir John Herschel as a machine for counting and recording the number of the oscillations of a pendulum; though to this definition we are obliged to add that every clock must also contain a mechanism adapted to maintain the state of oscillation of the pendulum against friction and the resistance of the air. A pedometer is an instrument for counting and recording the number of steps taken by the person carrying it. Distances along a road are approximately measured by rolling a wheel along the road, an apparatus being annexed to the wheel which counts and records its revolutions. In the same way a turnstile may be made to record the number of its own revolutions, *i.e.* the number of persons admitted through it.

The above are simple instances of counting machines employed for the common purposes of life; but the construction of calculating engines, adapted to more varied and complicated purposes than that of simple counting, is to be reckoned among the great achievements of mathematical and mechanical skill. The first idea of such a machine appears to have been due to the celebrated Blaise Pascal; the apparatus constructed by him was arranged for the addition and subtraction of sums of money. Two calculating machines, constructed in 1775 and 1777 by James Bullock for Viscount Mahon, are included in the Exhibition. But the idea of a difference engine, which should serve to calculate tables of analytical functions, was first successfully realised by Charles Babbage; the analogous contrivances which had previously been proposed having been designed merely for the performance of single arithmetical operations, such as addition, subtraction, multiplication, and division. The later years of Babbage's life were devoted to the construction, or rather to the design, of a great analytical engine, which was intended to possess a range of calcu-

lating power, far exceeding that of the difference engine, and, in fact, extending over the whole field of arithmetical analysis.

An article on Babbage's Difference Engine, in the *Edinburgh Review* for 1834, suggested to George Scheutz, of Stockholm, the idea of constructing a machine for simultaneously calculating and printing arithmetical tables. After many discouragements, which were overcome by the indefatigable perseverance of George Scheutz and his son Edward, this machine was at last completed in October, 1853. The "Specimens of Tables, calculated, stereo-moulded, and printed by Machinery," published by them in London in 1857, afford a convincing proof of the completeness and utility of their invention. Its originality was gladly recognised by Babbage; and indeed two things only are common to the engines of Babbage and Scheutz; the principle of calculation by differences, and the contrivance by which the computed results are conveyed to the printing apparatus.

Several arithmetical machines, on a smaller scale and of simpler construction, have been produced in recent years. Some of these are actually in use in the public offices of this country. We may mention especially the calculating machine of M. Thomas, of Colmar, and the panometer of Edward Grohmann, of Vienna.

In the ancient world, and before the invention of the decimal notation, the common operations of arithmetic were carried on with the aid of a "counting board," or *abacus*, the units being represented by counters, or pebbles (*calculi*, whence the word calculation). The authorities are not entirely agreed as to the precise arrangement of the ancient abacus, which, probably, was not always the same in all instances. It would seem certain, however, that the principle of decimal arrangement was to some extent adopted; counters in one compartment being valued as units, in that to the left of it as tens, and so on. It may seem strange that this partial introduction of a decimal system should not have led sooner to the invention of a decimal notation such as we now employ. The transition would probably have

been instantaneous if the idea of employing a distinct symbol for zero had occurred to those who used the abacus. But it is precisely the introduction of this symbol which forms the central point of the whole decimal notation; and it may be admitted that in the abacus itself there was nothing to suggest its introduction. The nearest approximations in the modern world to the ancient abacus are the bean-tables, multiplication boards, and other similar appliances employed in elementary education;* and the marking boards in use in certain games.

The monetary transactions of the ancient world were occasionally on a scale approaching those of our own times. When Vespasian became emperor he found that, after the profligate expenditure of Nero, and the subsequent civil wars, the indebtedness and pressing requirements of the imperial and public treasuries amounted to no less a sum than about three hundred and thirty millions sterling. However rudely the accounts of these vast liabilities may have been kept, they must have required an enormous amount of calculation; and all this calculation must have been performed with the abacus; for it would have been almost impossible with the written characters of the Roman system of numeration. Perhaps no single instance could better serve to show the great saving of human labour which has been effected by the use of a decimal notation.

The arithmetic of whole numbers, of which we are here speaking, has its theoretical as well as its practical part. This theoretical part is called the Theory of Numbers, and is perhaps the only branch of pure mathematics against which the charge of uselessness has ever been seriously alleged. Nevertheless, at all periods of the history of mathematical science it has excited a keen interest, and to it, rather than to researches of more obvious utility, we owe the development of the practical branch of arithmetic. As early as the second or third century before Christ, the

* A series of these appliances have been contributed to the Exhibition by the Committee of the Russian Pædagogical Museum.

Indian ritualists were led to the problem "To find two square numbers of which the sum shall also be a square" by the existence of a religious feeling which required that altars of different shapes should have the same superficial area. By these and similar inquiries, they were brought into contact with many questions of mensuration, and learned to solve them by approximate methods of considerable exactness; the value, for example, which they obtained for the side of a square equal to a circle of given diameter is correct as far as the third decimal place inclusively. Contemporary records of these researches still exist, and though they tell us of a time when science was in its infancy, they bear emphatic testimony to the genius and patient industry of the ancient workers. They are further characterized by that predominance of the arithmetical above the geometrical spirit, which forms so marked a contrast between the mathematical tendencies of India and of Greece. But while in these earlier treatises we can watch the growth of mathematical conceptions, called forth and fostered by the practical requirements of the old Vedic ceremonial, the purely scientific study of geometry and arithmetic in India belongs to a later period, probably to the fourth century after our era. Even then, the Hindus were the first to discover the method of solving indeterminate equations of the first degree, a method which was not known in Europe till the seventeenth century, and perhaps not demonstrated till the eighteenth. But the crowning achievement of Indian mathematical genius was the solution of the problem known as the Pellian Equation, upon which the analysis of indeterminate equations of the second degree may be said entirely to depend. The Indian mathematicians gave no demonstration of their solution. That demonstration was first given, at least fourteen hundred years later, by Lagrange, one of the greatest of European mathematicians, and the memoir in which he has recorded this discovery has always been regarded as one of the principal monuments of his genius. The indeterminate equation of the first

degree, to which we have above referred, is specially deserving of mention in this place, because it admits of mechanical applications to the theory of wheel-work, and also because it can be represented by a simple geometrical illustration.

We may mention, for a similar reason, another important research connected with the theory of numbers, viz., the calculation of Tables giving for each number the least number by which it is divisible; or, if it is a prime number, indicating that it is so. Such tables (which considerably abbreviate certain computations) have been constructed for the first nine millions; the tables of the fourth, fifth, and sixth millions exist, however, in manuscript only, and have never been published. The first attempt to form a Table of Primes was made by Eratosthenes, and the partly mechanical method adopted by him (and called after its inventor, "the sieve of Eratosthenes") has been adopted in principle, though with appropriate modifications, by his successors.

There is in general so little appearance in those laws of nature with which we are acquainted of any adherence to integral or whole numbers, that we may be allowed to call attention to two important classes of phenomena which form an exception to this remark. We refer to the laws of chemical combination, and to the laws of crystallography.

If we imagine chemical substances existing in the ideal condition of perfect gases, the law of chemical combination may be expressed in its most abstract form by saying that if two perfect gases combine chemically, and form a compound which is also supposed to exist in a perfectly gaseous condition, the volumes of the two gases before combination and of the gas resulting from their combination are to one another as three whole numbers.

The law of integral numbers to which the faces of a crystal are subject is sufficiently illustrated by the models in the section of mineralogy; and it would be out of place to discuss it here.

It may, however, be proper to remark that the whole numbers which present themselves in the formulæ whether of chemistry or

of crystallography are never very considerable. In the case of some organic bodies the number of equivalents that enter into the formula has to be counted by hundreds; but in all such instances, owing to the imperfection of the methods of chemical analysis, the determinations that have been given must be regarded as open to correction. The "indices" of any face of a crystal actually occurring in nature rarely exceed ten.

(2.) The geometrical and mechanical appliances for aiding in the operations of arithmetic, as applied to continuous magnitude, are not very numerous, and possess in most cases a theoretical rather than a practical importance.

A very ingenious instrument of this kind, and one that has been extensively used, is the slide rule, which may be described as an apparatus for effecting multiplications and divisions by means of a logarithmic scale; the requisite additions and subtractions being performed without calculation by a proper adjustment of the instrument itself. The principle on which it depends admits of being applied in various ways, and thus there are slide rules of very various forms, and adapted to very different purposes. But the card of four figure logarithms is a formidable competitor to any logarithmic scale, and it may be doubted whether at the present time these really beautiful contrivances are in as common use as they deserve to be. The Exhibition contains a complete series of them by Messrs. Aston and Mander; besides the Estimator of Dr. F. M. Stapff, and the Pocket Calculator of General De Lisle.

Instruments for solving triangles and for finding the roots of quadratic and higher equations may next be noticed. Some of them are remarkable for their ingenuity; some are useful as educational appliances, because they serve to illustrate, in a very beautiful way, the connection between arithmetic, or algebra, and geometry. Others again are of great interest from the difficulty of the problems which they propose to solve, and the profound character of the principles which they employ in the solution. To this last class belongs the interesting application by Professor Sylvester

of the Peaucellier movement to the extraction of the roots of numbers.

With regard to all these arrangements it must be observed that the solutions which they afford are only approximate, and that the degree of the approximation cannot be carried beyond a certain point. This arises, not from any imperfection in the theory of the instruments, but from the circumstance that the solution of the problem is given by measurement; and that all measurements are necessarily approximate, and subject to errors which cannot be reduced beyond a certain point.

In this respect the analytical solution of a problem possesses a great theoretical advantage above a solution obtained by geometrical or mechanical means. The analytical solution is indeed in general approximate, no less than the geometrical or mechanical one; but the degree of the approximation is no longer limited: for if we are dissatisfied with the degree of approximation we have obtained, we can go back and repeat the process over again, retaining small terms which we before omitted, until we arrive at a result as near to the truth as we please. Of course this theoretical advantage ceases to have any practical importance whenever the degree of approximation attainable by the mechanical appliance is sufficient for the purpose in view.

At an earlier stage of the development of analytical science, graphical methods for the solution of analytical problems were of more importance than they are at present. When Descartes showed that the solution of a biquadratic equation could be made to depend on the determination of the intersection of a parabola by a circle, it is possible that, at least in certain cases, the very best method of finding the roots of a proposed biquadratic equation, which the resources of mathematics could then supply, was to describe the parabola and the circle, and actually to measure the ordinates of the points common to the two. But the continual progress of improvement in analytical processes, coupled with the greatly increased facility in calculating the arithmetical values of analytical expressions,

which was obtained by the invention of logarithms, has completely outrun the present capabilities of geometrical methods; and these methods are now seldom used, except for obtaining rough first approximations. Thus it is that the degree of perfection which has been given to analysis has enabled it to dispense with mechanical aids; although instances are not wanting which may serve to show that the mechanical methods may yet receive a great future development. In addition to the applications of the Peaucellier movement, to which we have already referred, we may also mention that Sir William Thomson has recently planned an integrating machine which will integrate mechanically any differential equation, or set of simultaneous differential equations, containing only one independent variable. In the important case of the linear equation of the second order with variable coefficients, the actual construction of the requisite mechanism would, in the opinion of Sir William Thomson, present no insuperable difficulty. The kinematical principle employed in this integrating machine is due to Professor James Thomson, and consists in the transmission of rotation from a disk or cone to a cylinder by the intervention of a loose sphere, which presses by its weight on the disk and cylinder, or on the cone and cylinder, as the case may be; the pressure being sufficient to give the necessary frictional coherence at each point of rolling contact. Sir William Thomson proposes to apply this principle to the construction of a machine adapted to calculate the harmonic constituents of any given function; and he believes that by employing such a machine in the analysis of the ides a single operator will be enabled to find, in an hour or two, any one of the simple harmonic elements of a year's tides recorded in curves by an ordinary tide gauge in the usual manner, a result which hitherto has required not less than twenty hours' computation by skilled arithmeticians. As another indication of the same tendency to substitute (wherever it may be found possible) mechanical or graphical contrivances for abstract calculations, we may refer to an excellent German treatise, the "Graphische Statik" of

Professor Culmann, which has already exercised a powerful influence upon the course of technical education in Germany, and of which it is the object to solve important engineering problems, relating to the stability of constructions, by mere geometrical drawing, without the use of analytical formulæ.

HENRY J. S. SMITH.

GEOMETRICAL INSTRUMENTS AND MODELS.

NEXT to the science of number, the science of space is that which is at once the most abstract, and admits of the most universal application to the study of natural phenomena. Everything that takes place takes place in space ; and thus Geometry, or the science of space, necessarily intervenes in all exact observation of events.

When we begin to think about space at all, the properties of it which first impress the mind are its continuity, and its apparently indefinite extent, our imaginations being perhaps unable to conceive the absence of either of these two properties. Probably we next notice the existence of three dimensions of space (as seen in the length, breadth, and height of any object), and we cannot conceive it to possess more or fewer. We further observe, (1) that at any two different points space is exactly similar to itself, and (2) that in all the directions which exist at any one point it has identical properties.

These general assertions, if not really of themselves evident, are at least readily admitted as being in accordance with universal experience. They are all assumed in, and may be said to form the basis of, that analytical representation of space which we owe to Descartes, and which justly entitles him to be regarded as the founder of modern geometry. In accordance with this representation we regard space as a complex (if we may use this word as a translation of the German *mannigfaltigkeit*) of three indeterminate quantities corresponding to its three dimensions ; the surfaces,

lines, and points which exist in space, being, in technical phraseology, the "loci" obtained by imposing one, two, or three restrictive conditions upon these indeterminates. As often happens in similar cases, the mode of representation thus introduced is capable of being extended so as to apply to other objects or conceptions beside that for which it was first employed; and thus mathematicians have been led to consider complexes of more than three indeterminates, or, again, complexes not possessing the properties which we have enumerated as characteristic of space. This is the origin of such phrases as "a space of four dimensions," or of such assertions as "it is conceivable that a space may not be exactly similar to itself at all its points." These speculations are perhaps not calculated directly to promote our knowledge of the space in which we live and move, and to which they seem entirely inapplicable; but they have had the effect of advancing our knowledge of the relations of quantity, and have thus had an indirect, but not unimportant, influence upon the recent progress of geometrical science.

So great has been the influence of the Cartesian mode of representation upon geometrical speculation that it has perhaps, to a certain extent, and in certain cases, unduly led away the minds of geometricians from that direct intuition of space upon which geometry must after all be founded. And there can be no doubt that an Exhibition of models such as those included in the present Catalogue is calculated to render a great service to geometrical science by calling attention to the concrete shapes of objects, which are too apt, even in the mind of the serious student, to exist only as conceptions very imperfectly realised.

We may for the purposes of this introduction adopt a threefold classification of the properties of space, as being either, 1. Properties of Situation; or, 2. Graphical Properties; or, 3. Metrical Properties. Of each of these three classes of properties we shall here say a few words to illustrate their importance and meaning.

1. The Properties of Situation of a figure in space are those

which exist irrespectively of the magnitude and even of the shape of its parts, depending solely on the connection of the parts, and on their situation with reference to one another. As neither the term "properties of situation," nor the description which we have just given of these properties, can be regarded as conveying a distinct image, a few very simple examples of what is meant may not be out of place.

If we draw, upon any surface such as a plane, two closed contours of however complicated an outline, it is quite possible that they may never meet one another, or that they meet in one or more points, and do not traverse one another. But if they traverse one another at all, they must do so an *even* number of times; *i.e.* twice, or four, or six times, &c. The truth of this proposition will be easily admitted, and it will be seen that, to understand the assertion made, we require no conception of magnitude, nor even the conception of the straight line or plane. All that we require is the idea of a continuous closed curve, and of a surface upon which it is drawn.

Again: conceive of two bodies, one a hollow sphere, the other a hollow anchor ring, and let a person imagine himself placed successively in the interior of each of these two hollow bodies. The two closed spaces in which he will thus successively find himself differ from one another at least in one remarkable respect. There is but one way of travelling from one point A inside the sphere, to another point B, also inside it: we might, of course, trace any number of routes we please from A to B, but all these routes are really reducible to one and the same route; and an elastic thread connecting A and B might be stretched so as to assume the shape of any one of them. But now take two points A and B inside the hollow anchor ring, and it will be seen at once that there are two different ways, irreducible to one another, of travelling from A to B. We have thus before us an example of a *singly connected* space (the interior of the sphere), and a *doubly connected* space (the interior of the anchor ring). The distinc-

tion depends entirely on the properties of situation of the two bounding surfaces; and it is one which has been found to be of some importance in the theories of the motion of fluids, and of electricity.

As a third example, take an oblong strip of paper, and fasten its two ends together so as to form a portion of a cylindrical surface. Take another similar piece of paper, and again fasten its two ends together, but give the paper a half twist so as to bring the upper surfaces of the two ends in contact with one another. Between the surface thus formed, and the cylindrical surface at first obtained, an important distinction will be found to subsist; viz., the cylindrical surface has an outside and inside surface, and there is no way of passing from one to the other except by penetrating the paper or crossing its edge: whereas the two sides of the second surface form one perfectly continuous sheet; so that by travelling once along the whole length of the oblong strip, we should pass from a point on the surface to the point exactly corresponding to it on the other side of the surface; and we should not return again to the point from which we set out, until we had completed the tour a second time. The distinction which we thus learn to draw between surfaces which have two sides, and surfaces which have but one, is fundamental, and depends solely on the properties of situation of the figure, as we have now defined them.

No complete *corps de doctrine* has yet been formed of the properties of situation of figures. This is partly owing to the great difficulty of the inquiry, partly to the fact that it is only in very recent times that the attention of mathematicians has been called to the subject, by the unexpected light which researches into it have been found to throw on some of the most obscure questions of the integral calculus. We cannot, therefore, expect to find this part of the science of geometry extensively illustrated by models, or by drawings expressly prepared for the purpose. But any great collection of geometrical objects cannot fail to supply

examples of such properties; and, what is of more importance may be expected to suggest entirely new points of view in a branch of inquiry, which, more than almost any other within the range of pure mathematics, is dependent on direct observation.

2. The Graphical Properties of space are those which involve the conceptions of the straight line and plane, but do not involve any conception of magnitude, or of measurement. The Elements of Euclid will be searched in vain for an example of a purely descriptive theorem, though it would seem that one of the lost treatises of that great geometer—the "Porisms"—was devoted to this part of geometry. In modern times researches into the descriptive properties of figures were revived by Blaise Pascal, and his elder contemporary, Desargues. By a strange fatality, the purely geometrical works of these two eminent men were lost, or wholly neglected, for more than a century, and it is only in comparatively recent times that they have received the attention which they merited. We may take as a simple instance of a graphical theorem the proposition of Desargues: "If two triangles lying in the same plane are such that the lines joining their vertices taken in pairs meet in a point, the three intersections of the pairs of sides opposite to these vertices lie in a straight line; and conversely."

3. Lastly, the Metrical Properties of space are those which involve, implicitly or explicitly, the consideration of magnitude. Thus the old proposition of Pythagoras, "The square of the hypothenuse in a right angle is equal to the squares of the sides containing the right angle:" and the theorems of Archimedes, "The surface of a sphere is equal to the curved surface of its circumscribing cylinder; the volume of the sphere is two-thirds of the volume of that cylinder," are metrical propositions. They could not be made intelligible to a person who had not the conception of the equality of geometrical magnitudes; nor verified by any one who had not the means of making exact quantitative measurements; whereas the proposition of Desargues, above

quoted, is intelligible to any one who knows what a straight line and a plane are, and may be verified by any one who has a sheet of paper, a pencil, and a straight edge.

Comte proposed to define geometry as "la science qui a pour but la mesure des grandeurs." As a scientific statement this definition is probably insufficient, because a great part of geometry consists, as we have seen, in propositions which have no immediate connection with measurement. It must, indeed, be admitted that by far the most important applications of geometry to natural science, and to the business of life, turn on the metrical properties of figures. But, in a purely theoretical point of view, there is reason to believe that the graphical properties of space are the more universal, and deeply-seated in the nature of things, *notiora naturæ*, as Lord Bacon would have said; and that the metrical properties are, in a certain sense, secondary and derivative. As an example of the character of universality, which we thus attribute to graphical properties, we may take the general principle of the *duality* (as it has been termed) of geometrical figures. This principle asserts that all purely graphical theorems are twofold; *i.e.* that any graphical proposition relating to points and planes in space gives rise to another, which is correlative to it, but in which the points have been replaced by planes, and *vice versâ*: the line joining two points being replaced by the line of intersection of two planes.

We proceed to indicate the principal classes of material appliances which are of use in geometrical investigations, or in the applications of geometry to the arts, or lastly, in its employment as a means of education.

We shall mention successively—.

A.—Instruments used in geometrical drawing or mapping, and in copying geometrical drawings or maps.

B.—Instruments used in tracing special curves.

C.—Models of figures in space.

D.—Modes of representing figures in space by means of plane drawings.

A.—Instruments used in Geometrical Drawing.

The Ruler and the Compasses—the two great instruments of geometrical drawing and construction—are of a very remote antiquity. Probably a stretched string—such as is still used by carpenters—was the earliest form of apparatus for obtaining a straight line; and a string attached to a peg (a contrivance still adopted by gardeners in laying out a flower-bed) afforded the earliest means of describing a circle. Compasses such as we now use, and indeed several of very different forms, have been found in the excavations of Pompeii. But it is probable that the use of the compasses, which is now universal, for transferring with exactness measured lengths from a scale to a drawing, or from one drawing to another, was hardly practised in ancient times. Had this practice prevailed, it is difficult to suppose that it would not have superseded the second and third problems of the First Book of Euclid, in which lengths are transferred by means of the actual description of circles.

Among more recent improvements in the construction of compasses we may notice (1) the arrangements adapted for very fine work, and known as hair-compasses, needlepoint compasses, and spring-dividers; (2) the proportional or reducing compasses, by which we are enabled to reduce or augment in any given ratio the distances which we transfer from one drawing to another; (3) the triangular compasses, by which the position of three points forming a triangle can be transferred from one drawing to another, and which thus serve as an instrument for transferring angles; (4) the beam compasses, consisting of a beam or bar, along which the two points of the instrument may be moved backwards and forwards, the distance between them admitting of adjustment with great precision, by means of a micrometer screw.

Next in the universality of its employment in all geometrical

plan drawing is the scale of equal parts. Let one pair of opposite sides of a rectangle be divided, say, into ten equal parts, the points of division on each being numbered 1, 2, 3, . . 9, and let the lines 11, 22, 33, . . 99, be drawn parallel to the sides of the rectangle. Let the other pair of opposite sides be similarly divided into ten equal parts, but let the points of division be joined in a slanting direction by the parallels 01, 12, 23, 34, . . . ; it will be found that the first set of parallels are divided into hundredths by the second set. Such a diagonal scale is placed on every so called *plane scale*, and serves to divide one of the primary divisions into hundredth parts. With a fine pair of compasses, we may succeed in taking off from the scale any required length with an error perhaps not exceeding one five hundredth part of a primary division of the scale.

Besides the scale of equal parts, the plane scale usually has engraved upon it a scale of chords, and a protracting scale. These are the simplest known contrivances for setting off an angle, given in degrees and minutes, or for approximately measuring an angle already laid down. With a good scale of chords, an angle can, it is said, be set off true to the nearest minute. But, for the best and most convenient solution of the problem, "to construct an angle equal to a given one," we have recourse to the divided circles, or parts of circles, known as circular, or semicircular, or quadrantal, protractors.

Less elementary in their theory than the preceding simple instruments, are the arrangements called Pantographs, which enable us to copy any given plane figure upon a different scale. Of this instrument there are two principal forms, known as the older pantograph and the Milan pantograph. In each of these there is a linkage movement in which only one point is absolutely fixed. The linkage is so arranged that two points on different bars always remain in the same straight line with the fixed point, and at distances from it which are to one another in a constant ratio. It follows from this that if one of these two points be made

to describe any figure, the other will describe a similar and similarly situated figure, the centre of similitude of the two figures being the fixed point. In the older pantograph the similarity is direct, in the Milan pantograph it is inverse; *i.e.* in the first case the figures are on the same side of their centres of similitude, in the second they are on opposite sides.

B.—Instruments for Tracing Special Curves.

Geometrical drawings consist very mainly, but not exclusively, of straight lines and circles. And the same limitation is observable in all the ordinary constructions of theoretical geometry. It has been ascertained that every problem which admits of one solution, and one only, can, if the data of it are given graphically, be solved with the ruler only, *i.e.* by drawing straight lines only, and without using the compasses; and, again, that every problem which is *quadratic*, *i.e.* which admits two solutions, but not more, can be solved with the ruler and compasses. Indeed, it is further known that, for this purpose, one circle, traced once for all, would, as a matter of theory, be sufficient.

These considerations are perhaps sufficient to account for the great preponderance of importance which attaches, in theoretical geometry, to the straight line and circle. On the other hand, the straight line and circle possess in common a property which is peculiar to them among all plane curves, and which is invaluable in all the practical applications of geometry. They are the only plane (or untwisted) lines any part of which can be applied exactly to any other. In very many mechanical arrangements this property is indispensable, and it is advantageous in all cases where accuracy of form is required, because it offers a simple means of verifying that accuracy has been obtained. There is but one twisted curve which has the same property, viz., the helix, or screw-curve, and it is precisely because any part of a screw-curve can be superposed upon any other that the screw and nut

arrangement is possible, which renders this curve of so much use in mechanics.

But notwithstanding these prerogatives of the straight line and circle, the tracing of other curves is occasionally indispensable both in theoretical and practical geometry. It is by no means an easy matter to invent a good method of tracing a curve. Even when the theory of a curve is pretty well known, that theory may fail to suggest any mode of describing it mechanically; and not every mode which theory suggests can be made to work accurately in practice. Of all curves, after the circle, the ellipse would seem to be the simplest and easiest to draw, but some authorities on the subject recommend the draughtsman not to attempt a true ellipse, but to put together an imitation semi-ellipse, by means of six or seven arcs of circles with centres and radii appropriately chosen. It is said that such an imitation will impose even on a well-trained eye, although it is plain that, whereas the curvature of an ellipse changes continuously, the curvature of the imitation curve changes abruptly at the points of junction of the circular arcs.

The discovery of M. Peaucellier that a linkage can be constructed capable of describing a straight line may perhaps hereafter revolutionise this part of geometry. Already it is known that any conic section, and several of the more important curves of the third and fourth orders can be described by linkage movements, or compound compasses, as M. Peaucellier has called them, not too complicated to work steadily. Theoretically, the results obtained are of a far wider scope, and Professor Sylvester has shown good reason for believing that every geometrical curve is capable of being described by a link-movement.

We may briefly mention some other mechanical arrangements which exist for describing certain plane curves.

(1.) The ellipse can hardly be described with great accuracy by means of a thread attached to its two foci and stretched by a pencil, because of the extensibility of the thread. It can be described as an hypocycloid, as in the apparatus of Mr. A. E. Donkin; or

we may use the old-fashioned elliptic trammels, or some other form of elliptic compasses of more recent invention. If none of these arrangements are at hand, perhaps the best way to obtain easily a really good ellipse is to take an oblique section of a carefully turned cylinder. All the three conic sections can be described by means of the conograph of Dr. Zmurko, of Lemberg.

(2.) The cycloid is the curve traced by a point in the circumference of a circle rolling on a straight line; the epicycloid and hypocycloid are traced in the same way, only that the rolling circle rolls on the outside or inside of a circle instead of on a straight line. These definitions have suggested various modes of describing these curves mechanically; an interesting cycloidograph is exhibited by Dr. Zmurko.

(3.) Mr. A. G. Donkin has constructed a beautiful apparatus for tracing harmonic curves. This machine will draw as many different forms of the curve $y = a \sin (m\,x + \alpha) + b \sin (n\,x + \beta)$ as there are means for varying the constants a, b, m, n, α, β: the number of variations being practically unlimited, except in the case of m and n, which are the numbers of teeth in certain wheels of which only a limited number of changes can be provided. Thus the machine exhibits to the eye the effect of the composition of two harmonic curves of any different intensities and phases, and of different intervals.

(4.) Several forms of spirals (or volutes) are of use in the arts, and appropriate modes of describing them have been given. Among these curves we may select for special notice the involute of the circle, which gives the proper form for the teeth of toothed wheels.

(5.) We may refer, lastly, to the epicycloidal curves of Mr. Perigal; and to the beautiful diagrams, not properly epicycloidal, but of a more complicated type, obtained by his compound geometric chuck.

C.—Models of Figures in Space.

Models of certain geometrical solids, for example, of the so-called three round bodies—the sphere, the right cone, and the right cylinder; of the five regular solids—the tetrahedron, the cube, the octahedron, the dodecahedron, and the icosahedron; and of the various forms of prisms, pyramids, and parallelepipeds, have been long in use as educational appliances.* All these geometrical forms have been well known to mathematicians from very ancient times; surprising as it may appear that researches into the nature of such solids as the dodecahedron and icosahedron should have preceded other inquiries of a more elementary and at the same time of a more important character.

In very recent times the great development of geometrical speculation has led to the effort to reproduce in a material shape a much greater variety of geometrical conceptions. We proceed to enumerate some of the more important classes of objects of this kind.

(1.) Models of surfaces of the second order.

Among these, two of the central surfaces, the ellipsoid and the hyperboloid of one sheet, have occupied a great place in the recent history of geometry. We may mention a few important theoretical considerations which models of these surfaces have served to illustrate.

The curvature of a surface at any point is either such that the surface at that point is entirely concave on one side and convex on the other, or else it is such that the surface on each side alike is partly convex and partly concave. A sphere is an example of a surface of the first kind; the upper surface of a saddle may serve as an instance of curvature of the second kind. But the ellipsoid and the hyperboloid furnish perfect typical examples of these two kinds of curvature.

At any point of a surface there are always two directions at

* A complete collection of such models, made by Stronkoff, is exhibited by the Committee of the Russian Pedagogical Museum.

right angles to one another, along one of which the curvature is the greatest, and along the other the least. At special points, called umbilics, the greatest and least curvatures (and therefore all the curvatures) are equal to one another. The sphere has the peculiarity that every point on it is an umbilic; on the sphere, therefore, there are no directions of greatest and least curvature; but on every other surface two series of curves can be drawn, cutting one another at right angles, and indicating for each point of the surface the directions of the greatest and least curvature. These lines are called the lines of curvature; they are, it may be said, detected by the eye itself on any surface. The ellipsoid has four umbilics; if a thread, attached to any two of these, be strained along the surface by a moving pencil, the pencil will describe a line of curvature, so that when the ellipsoid has once been modelled, and its umbilics determined, it is easy to draw its lines of curvature with sufficient approximation. It was suggested long ago by Monge that a semi-ellipsoidal vault would form the most appropriate covering for an oval room, that the natural lines of the vaulting would be the lines of curvature, and that the umbilics would be the proper centres of illumination.

Every surface of the second order is either *umbilical* or *rectilineal; i.e.*, it either possesses umbilics, or it is capable of being generated by the motion of a straight line: it cannot unite both properties. The ellipsoid, as we have just seen, is umbilical; the hyperboloid of one sheet is rectilineal; and the two systems of straight lines which lie upon this surface are very conspicuous in any model of it. It will be seen that one line of each system passes through each point on the surface; but that no two lines of the same system ever meet one another. The hyperbolic paraboloid, which may be regarded as a variety of the hyperboloid of one sheet, is characterized by similar properties: the Exhibition includes a beautiful series of models of these two surfaces made by M. Fabre de Legrange, in 1872, for the South Kensington Museum. A series of cardboard models of surfaces of the second

order (the cone, the cylinder, the ellipsoid, the hyperboloids, and both the paraboloids) is also exhibited by Professor Henrici, of University College, and by Professor Brill, of Munich. These models exhibit very clearly the circular sections of the various surfaces, having, indeed, been constructed by means of them; with the exception of the hyperbolic paraboloid, in which (as well as in the hyperbolic and parabolic cylinders) such sections (strictly speaking) do not exist.

(2.) Models of surfaces of the third order.

Nothing like a complete series of models of surfaces of the third order has as yet been attempted; and indeed it may be said that our knowledge of these surfaces is still too imperfect to justify such an attempt. Nevertheless, models of certain of these surfaces have been made, and we may mention a few important properties which they serve to illustrate.

(*a.*) As we have already said, the two curvatures of an ellipsoid at any point upon the surface are turned the same way, whereas the two curvatures of an hyperboloid are everywhere turned opposite ways. But, generally speaking, a curve surface consists of two regions, on one of which its two curvatures are turned the same way, and on the other opposite ways. These two regions are separated by a bounding line, technically called the parabolic curve. Surfaces of the third order offer typical examples of these general geometrical facts. But an example, though of a less perfect kind, is afforded by the figure of a ring (such as an anchor ring, or a wedding-ring); the parabolic curve here consisting of either of the two circles on which the ring would rest if placed lying on a horizontal plane.

(*b.*) Wherever the two curvatures of a surface are opposite to one another, there always exist upon the surface two sets of lines along which the surface is inflected; *i.e.* at any point of the surface these two lines separate the directions in which the curvature is turned one way from those directions in which it is turned the other way. On the hyperboloid these "curves of principal tan-

gents," as they are called by the German writers, are represented by the rectilinear generators; on surfaces of the third order we have the simplest examples of the general case in which they are not straight, but curved. The eye can just recognise these curves upon a surface, though of course in an approximate manner. The two which pass through any point are equally inclined to the lines of curvature at that point; they have a theoretical importance, even greater than that of the lines of curvature, because their definition is graphical, and not metrical.

(*c.*) As a general rule, three lines of curvature pass through an umbilic. On the surfaces of the second order this property of the umbilics does not exist; and the first example of it occurs on surfaces of the third order. It is clearly seen in Professor Henrici's model of the cubic surface $xyz = k^3(x + y + z - 1)^3$.

(*d.*) A model of a surface of the third order ought to exhibit to the eye one of the most characteristic properties of these surfaces; *i.e.* that of containing a certain finite number of straight lines. The maximum number of these lines is twenty-seven; and the model exhibited by Dr. Wiener has this maximum number. A model, showing the distribution in space of the lines themselves, unaccompanied by the surface on which they lie, has been constructed by Professor Henrici.

In the model (*c*) to which we have just referred, the twenty-seven lines are all real, but are coincident in sets of nine; so that there appear to be three only.

(3.) Models of ruled, or rectilinear surfaces.

Ruled, or rectilinear surfaces are those which may be generated by the continuous motion of a straight line in space, and which therefore may be said to consist of an infinite number of straight lines. Models of these surfaces exist in great variety, because they can be constructed with threads or wires, instead of being carved out of a solid material, or moulded out of a plastic one. They are, of course, only approximate or diagrammatic, the generating lines being represented in such number only as may suffice

to convey to the eye an accurate impression of the form of the surface. Rectilinear surfaces are of two very different kinds, being termed skew, or developable, according as the successive generating lines intersect or not. Of skew surfaces the hyperboloid may be taken as an example: it may be defined as the surface generated by the motion of a straight line, which moves so as always to intersect three fixed straight lines which do not meet in space. In the hyperbolic paraboloid the generating line always intersects two fixed straight lines, and is always parallel to a fixed plane: this surface is the simplest example of the family of skew surfaces called conoids. The series of M. Fabre de Lagrange contains several models of conoidal surfaces; they are all generated by the motion of a straight line, which (1) continually remains parallel to a fixed plane, and which also (2) continually intersects a fixed straight line, and (3) some other fixed line in space. The surface of the thread of a square cut screw (or, more precisely, the surface formed by drawing lines from all the points of a screw curve perpendicular to the axis of the screw), affords a familiar instance of a conoidal surface. In the "Skew Helixoid" of M. Fabre de Lagrange the lines drawn from the points of the screw curve to the axis are not perpendicular to the axis, but are inclined to it at a constant angle. The recent progress of geometry has led to a careful study of the skew surfaces of the third, fourth, and fifth orders: of some of these, models have been already made; one of the cubic surface, called the cylindroid, is exhibited by Dr. Ball, Royal Astronomer of Ireland.

Developable surfaces form a class of surfaces entirely *sui generis*. They are called *developable* because, if such a surface consist of a flexible and inextensible membrane, it can be "developed," or flattened out, upon a plane, without any tearing or crumpling. Cones and cylinders are the simplest instances of developable surfaces, but they are far from giving a complete idea of the general character of these formations. A more typical instance may be obtained by considering all the lines tangent to any twisted

curve. It will be found that these tangents all form a developable surface, and that the twisted curve is an edge-curve or cuspidal line upon the surface. This edge-curve is characteristic of a developable: in the cone it dwindles to a point, and in the cylinder this point lies at an infinite distance. Since a developable surface, when made to roll on a plane or on another developable surface, has a *line* of contact with it, whereas in general two surfaces made to roll on one another have only a *point* of contact, it is easy to see that these surfaces are of great importance in the arts of construction. But, in a theoretical point of view, it is even more important to notice what is rendered visible by any model of such a surface:—(1) that at each point of the surface one of the two curvatures is infinite, the generating line being always one of the lines of curvature; (2) that, whereas in other surfaces each tangent plane has an infinite number of tangent planes lying near to it (because we can travel from any point on the surface to an adjacent point in an infinite number of different directions), in the case of developable surfaces this is not so, but each tangent plane is preceded and followed by only one other tangent plane; these planes, in fact, forming a singly, instead of a doubly, infinite series. It follows from this, that in the duality of space there answers to a developable surface a curve line, whereas to any surface not developable there answers a surface not developable. As an example, easy to understand and to remember, of a developable surface, we may mention the "Developable Helixoid" of M. Fabre de Lagrange.

Most of the models of ruled surfaces to which we have referred are so arranged as to be capable of *deformation; i.e.*, their shape can be changed by altering the form, or the relative position, of the director curves or straight lines, which serve to regulate the motion of the generating straight line. Thus the same model is rendered capable of assuming in succession the forms of several different surfaces; and the study of the transformations by which we pass from one of these forms to another is of great interest and

importance. The cardboard models of Professor Henrici admit of deformation in a similar manner, since the angle at which the two planes of circular section are inclined to one another may be changed.

(4.) Models of certain Special Surfaces.

(*a*) The Surfaces of Plücker.

In very recent times the properties of systems of lines in space have been studied with great ardour, chiefly by the German geometers. The consideration of such systems is suggested by many geometrical problems (for example, the study of the straight lines which cut a given surface at right angles, the so-called normals of the surface), but it is also forced upon our notice in all those optical researches in which the properties of systems of rays form the subject of inquiry. A further interest attaches to the study of systems of straight lines in space, inasmuch as an examination of their properties would seem to be an indispensable preliminary to the more general inquiry into the properties of systems of curves; such systems of curves meeting us at every turn in Physics; as stream lines in Hydrodynamics, as lines of flow in the theory of the conduction of Heat, as lines of force in the theories of Electricity and Magnetism.

The present Collection contains a beautiful series of models of a class of surfaces which are found to play an important part in the theory of rectilinear systems. A certain historical interest attaches to these models; they are copies of those exhibited in 1866, at the Nottingham Meeting of the British Association, by the celebrated mathematician, Julius Plücker, to whom, more than to any other single person, we are indebted for our knowledge of the geometry of systems of lines. They were made by Epkens, of Bonn, and were presented by Dr. Hirst to the London Mathematical Society. Professor Hennessy, of the Royal College of Science for Ireland, also exhibits a series of models illustrative of the researches of Plücker.

(*b*) The Wave Surface.

The importance of this surface in the undulatory theory of Light forms its principal claim to attention. But, even apart from any physical interpretation, its geometrical properties entitle it to a place in a collection of geometrical models. It furnishes us with an instance of a closed surface of two sheets, one of them lying inside in the other; it is an *apsidal* surface, and its reciprocal surface is a surface of the same nature as itself; finally, it offers typical examples of the singularity termed a conical node: and of the correlative singularity of a tangent plane touching a surface along a conic section (in the case of the wave surface the conic section is a circle). The geometrical study of these singularities led Sir William Rowan Hamilton to his celebrated discovery of the optical phenomena of external and internal conical refraction.

(*c*) The Surface of Steiner.

Professor Cayley exhibits a rough model of this surface, which has attracted considerable attention among mathematicians, from its being the polar reciprocal of the cubic surface with four conical nodes, and from its having the property that every one of its tangent planes cuts it in two conic sections.

(*d*) The Amphigenous Surface of Professor Sylvester.

This surface is of great importance in the theory of equations of the fifth order. A model of it has been prepared by Professor Henrici.

(*e*) Surfaces of constant curvature.

The total curvature of a surface at any point is the product of its two principal curvatures at that point; and the total curvature is positive or negative, according as the two principal curvatures are in the same direction or in opposite directions. It is an important geometrical theorem, that if two inextensible and flexible surfaces have at corresponding points the same total curvature, either of them can be "developed" upon the other without tearing or crumpling. Thus every surface of constant positive curvature can be developed upon a sphere. Surfaces of constant negative curvature cannot, of course, be developed upon a sphere; but

they possess a great theoretical interest of their own, since it has been ascertained that the geometry of figures traced upon these surfaces, is precisely that which the geometry of Euclid would become, if we were to erase from it the assumption known as the eleventh axiom. Models of both these classes of surfaces are contributed by Professor Henrici.

(5.) Crystallographic Models.

These are either models of those geometric polyhedra (solids bounded by plane faces) which actually occur in nature; or they are intended to serve as illustrations of the theory of crystallography, and to exhibit the relations of the plane faces of a crystal to its crystallographic axes.

D.—Representations of Figures in Space by means of Drawings on a Plane.

We have lastly to refer to modes of representation by drawings on a plane of figures in space. We have here at our disposal the ordinary methods of perspective; but the practical use of these is too dependent on the hand and eye of the artist to satisfy the requirements of geometrical rigour. The method known as "Descriptive Geometry" is therefore preferred for the purposes of geometrical drawing. This method consists in representing an object in space, by means of its orthogonal projections on two planes at right angles to one another. It therefore can hardly be said to be of recent date, as, in principle, it comes to representing a figure in space by a plan and elevation. But to Monge is perhaps due the idea of placing the plan and elevation on one sheet, and treating them (for the purpose of geometrical construction) as one plane figure; and to him is certainly due the development of the principles of the method into a complete and scientific system. The volumes of plates which accompany works on descriptive geometry (of which, since the time of Monge, there have been a considerable number) offer copious and varied illustrations of the method. But models have also been constructed, which serve to

exhibit to the student the relations of the object represented to its two projections, and of these to one another. We may refer, among others, to the diagrams and models exhibited by Professor Franz Tilser, of Prague, by Professor O. Reynolds, of the Owens College, Manchester, by the Committee of the Russian Pædagogical Museum, and by Professor Pigot, of the Royal College of Science for Ireland.

The *épures* of descriptive geometry, however accurate, and however useful for constructive purposes, do not offer much assistance to the imagination in conceiving complicated geometrical figures. Such assistance, however, is abundantly afforded by stereoscopic representations; and it is earnestly to be hoped that the applications of stereoscopy to geometry may hereafter receive a much greater development than has been the case as yet. Any polyhedron can (as is well known) be represented with extraordinary beauty by stereoscopy; the edges only of the polyhedron being drawn on the two faces of the stereoscopic slide. It ought in the same way to be possible to represent any twisted curve; and further, any developable surface, by representing first the twisted curve which forms its cuspidal line, and then a sufficient number of the straight lines tangent to that curve. Similarly to represent a skew rectilineal surface, it would be sufficient to exhibit stereoscopically a certain number of its generating lines. Surfaces which are not rectilinear could, theoretically at least, be represented by a sufficient number of their lines of curvature, or by means of their curves of principal tangents, when those curves exist. It must be admitted, however, that the accurate tracing of the plane diagrams which would be required for such representations would be subject to very serious practical difficulties, which it would be desirable to avoid by using special methods adapted to each particular surface; for example, in the case of the ellipsoid and the other umbilical surfaces of the second order, by employing the two systems of circular sections.

HENRY J. S. SMITH.

INSTRUMENTS USED IN MEASUREMENT.

By *Measurement*, for scientific purposes, is meant the measurement of *quantities*. In each special subject there are quantities to be measured; and these are very various, as may be seen from the following list of those belonging to geometry and dynamics.

Geometrical Quantities.

Lengths
Areas
Volumes
Angles (plane and solid)
Curvatures (plane and solid)
Strains (elongation, torsion, shear).

Circumstances of Motion.	*Properties of Bodies.*
Time	Mass
Velocity	Weight
Momentum	Density
Acceleration	Specific gravity
Force	Elasticity (of form and volume)
Work	Viscosity
Horse-power	Diffusion
Temperature	Surface tension
Heat.	Specific heat.

Notwithstanding the very different characters of these quantities, they are all measured by reducing them to the same kind of

quantity, and estimating that in the same way. Every quantity is measured by finding a *length* proportional to the quantity, and then measuring this length. This will, perhaps, be better understood if we consider one or two examples.

The measuremcnt of *angles* occurs in a very large majority of scientific instruments. It is always effected by measuring the *length of an arc* upon a graduated circle; the circumference of this circle being divided not into inches or centimeters, but into degrees and parts of a degree—that is, into aliquot parts of the whole circumference.

As a step towards their final measurement, some quantities, of which work is a good instance, are represented in the form of *areas;* and there seems reason to believe that this method is likely to be extended. Instruments for measuring areas are called Planimeters; and one of the simplest of these is Amsler's, consisting of two rods jointed together, the end of one being fixed and that of the other being made to run round the area which is to be measured. The second rod rests on a wheel, which turns as the rod moves; and it is proved by geometry that the area is proportional to the distance through which the wheel turns. Thus the measurement of an area is reduced to the measurement of a length.

Volumes are measured in various ways, but all depending on the same principle. Quantities of earth excavated for engineering purposes are estimated by a rough determination of the shape of the cavity, and the measurement of its *dimensions*, namely, certain lengths belonging to it. The contents of a vessel are sometimes gauged in the same way; but the more accurate method is to fill it with liquid and then pour the liquid into a cylinder of known section, when the quantity is measured by the height of the liquid in the cylinder, that is, by a length. The volumes of irregular solids are also measured by immersing them in liquid contained in a uniform cylinder, and observing the height to which the liquid rises; that is, by measuring a length. An apparatus for

this purpose is called a Stereometer. The liquid must be so chosen that no chemical action takes place between it and the solid immersed, and that it wets the solid, so that no air bubbles adhere to the surface. Thus mercury is used in the case of metals by the Standards Department.

Time is measured for ordinary purposes by the length of the arc traced out by a moving hand on a circular clock-face. For astronomical purposes it is sometimes measured by counting the ticks of a clock which beats seconds, and estimating mentally the fractions of a second; and in cases where the period of an oscillation has to be found, it is determined by counting the number of oscillations in a time sufficient to make the number considerable, and then dividing that time by the number. But by far the most accurate way of measuring time is by means of the line traced by a pencil on a sheet of paper rolled round a revolving cylinder, or a spot of light moving on a sensitive surface. If the pencil is made to move along the length of the cylinder so as to indicate what is happening as time goes along, the time of each event will be found when the cylinder is unrolled by measuring the distance of the mark recording it from the end of the unrolled sheet, provided that the rate at which the cylinder goes round is known. In this way Helmholtz measured the rate of transmission of nerve-disturbance.

A very common case of the measurement of *force* is the barometer, which measures the pressure of the atmosphere per square inch of surface. This is determined by finding the height of the column of mercury which it will support (mercurial barometer), or the strain which it causes in a box from which the air has been taken out (aneroid barometer). The height in the former case may be measured directly, or it may first be converted into the quantity of turning of a needle, and then read off as length of arc on a graduated circle; in the latter case the strain is always indicated by a needle turning on a graduated circle.

The *mass*, and (what is proportional to it) the *weight*, of different

bodies at the same place, are measured by means of a balance; and at first sight this mode of measurement seems different from those which we have hitherto considered. For we put the body to be weighed in one scale, and then put known weights into the other until equilibrium is obtained or the scale turns, and then we count the weights. But in a steelyard the weight is determined directly by means of a length; and in a balance which is accurate enough for scientific purposes, both methods are employed. We get as near as we can with the weights, and then the remainder is measured by a small rider of wire which is moved along the beam, and which determines the weight by its position; that is, by the measurement of a length.

For the measurement of weight in different places a spring-balance has to be used, and the weight is determined by the alteration it produces in the length of the spring; or else the length of the seconds pendulum is measured, from which the force of gravity on a given mass can be calculated. This last is an example of a very common and useful mode of measuring forces called into play by displacement or strain; namely, by measuring the period of the oscillations which they produce.

It seems unnecessary to consider any further examples, as all other quantities are measured by means of some simple geometrical or dynamical quantity which is proportional to them; as temperature by the height of mercury in a thermometer, heat by the quantity of ice it will melt (the volume of the resulting water), electric resistance by the length of a standard wire which has an equivalent resistance. It only remains to show how, when a length has been found proportional to the quantity to be measured, this length itself is measured.

For rough purposes, as for example in measuring the length of a room with a foot-rule, we apply the rule end on end, and count the number of times. For the piece left, we should apply the rule to it and count the number of inches. Or if we wanted a length expressed roughly for scientific purposes, we should describe it in

metres or centimetres. But if it has to be expressed with greater accuracy, it must be described in hundredth, or thousandth, or millionth parts of a millimetre; and this is still done by comparing it with a scale.

But in order to estimate a length in terms of these very small quantities, it must be *magnified;* and this is done in three ways. First, geometrically, by what is called a vernier scale. This is a movable scale, which gains on the fixed one by one-tenth in each division. To measure any part of a division, we find how many divisions it takes the vernier to gain so much as that part; this is how many tenths the part is. The quantity to be measured is here geometrically multiplied by ten. Next, optically, by looking at the length and scale with a microscope or telescope. Third, mechanically, by a screw with a disc on its head, on which there is a graduated rim, called a micrometer screw. If the pitch of the screw is one-tenth and the radius of the disc ten times that of the screw, the motion is multiplied by one hundred. The two latter modes are combined together in an instrument called a micrometer-microscope. Another mechanical multiplier is a mirror which turns round and reflects light on a screen at some distance, as in Thomson's reflecting galvanometer.

Properly speaking, however, any description of a length by counting of standard lengths is imperfect and merely approximate. The true way of indicating a length is to draw a straight line which represents it on a fixed scale. And this is done by means of self-recording instruments, which measure lengths from time to time on a cylinder in the manner described above. It is only by this graphical representation of quantities that the laws of their variation become manifest, and that higher branch of measurement becomes possible which determines the nature of the connection between two simultaneously varying quantities.

W. K. CLIFFORD.

INSTRUMENTS ILLUSTRATING KINEMATICS, STATICS, AND DYNAMICS.

Science of Motion.

GEOMETRY teaches us about the sizes, the shapes, and the distances of things; to know sizes and distances we have to measure *lengths*, and to know shapes we have to measure *angles*. The science of *Motion*, which is the subject of the present sketch, tells us about the changes in these sizes, shapes, and distances which take place from time to time. A body is said to move when it changes its place or position; that is to say, when it changes its distance from surrounding objects. And when the parts of a body move relatively to one another, *i.e.* when they alter their distance from one another, the body changes in size, or shape, or both. All these changes are considered in the science of motion.

Kinematics.

It is divided into two parts; the accurate description of motion, and the investigation of the circumstances under which particular motions take place. The description of motion may again be divided into two parts, namely, that which tells us *what* changes of position take place, and that which tells us *when* and *how fast* they take place. We might, for example, describe the motion of the hands of a clock, and say that they turn round on their axes at the centre of the clock-face in such a way that the minute-hand always moves twelve times as much as the hour-hand; this is the first part of the description of the motion. We might go on to say that when the clock is going correctly this motion takes place uniformly, so that the minute-hand goes round once in

each hour; and this would be the second part of the description. The first part is what was called Kinematics by Ampère; it tells us how the motions of the different parts of a machine depend on each other in consequence of the machinery which connects them. This is clearly an application of geometry alone, and requires no more measurements than those which belong to geometry, namely, measurements of lines and angles. But the name Kinematics is now conveniently made to include the second part also of the description of motion—when and how fast it takes place. This requires in addition the measurement of *time*, with which geometry has nothing to do. The word Kinematic is derived from the Greek *kinēma*, "motion;" and will therefore serve equally well to bear the restricted sense given it by Ampère, and the more comprehensive sense in which it is now used. And since the principles of this science are those which guide the construction not only of scientific apparatus, but of all instruments and machines, it may be advisable to describe in some detail the chief topics with which it deals.

Dynamics. That part of the science which tells us about the circumstances under which particular motions take place is called *Dynamics*. It is found that the change of motion in a body depends on the position and state of surrounding bodies, according to certain simple laws; when considered as so depending on surrounding bodies, the rate of change in the quantity of motion is called *force*. Hence the name Dynamic, from the Greek *dynamis*, "force." The word *force* is here used in a technical sense, peculiar to the science of motion; the connection of this meaning with the meaning which the word has in ordinary discourse will be explained further on.

Statics and Kinetics. Dynamics are again divided into two branches; the study of those circumstances in which it is possible for a body to remain at rest is called Statics, and the study of the circumstances of actual motion is called Kinetics. The simplest part of Statics, the doctrine of the Lever, was successfully studied

before any other part of the science of motion, namely, by Archimedes, who proved that when a lever with unequal arms is balanced by weights at the ends of it, these weights are inversely proportional to the arms. But no real progress could be made in determining the conditions of rest, until the laws of actual motion had been studied.

Translation of Rigid Bodies. Returning, then, to the description of motion, or Kinematics, we must first of all classify the different changes of position, of size, and of shape, with which we have to deal. We call a body *rigid* when it changes only its position, and not its size or shape, during the time in which we consider it. It is probable that every actual body is constantly undergoing slight changes of size and shape, even when we cannot perceive them but in Kinematics, as in most other matters, there is a great convenience in talking about only one thing at a time. So we first of all investigate changes of position on the assumption that there are no changes of size and shape; or, in technical phrase, we treat of the motion of rigid bodies. Here an important distinction is made between motion in which the body merely travels from one place to another, and motion in which it also turns round. Thus the wheels of a locomotive engine not only travel along the line, but are constantly turning round; while the coupling-bar which joins two wheels on the same side remains always horizontal, though its changes of position are considerably complicated. A change of place in which there is no rotation is called a *translation*. In a rotation the different parts of the body are moving different ways, but in a translation all parts move in the same way. Consequently, in describing a translation we need only specify the motion of any one particle of the moving body; where by a *particle* is meant a piece of matter so small that there is no need to take account of the differences between its parts, which may therefore be treated for purposes of calculation as a point.

We are thus brought down to the very simple problem of describing the motion of a point. Of this there are certain cases

which have received a great deal of attention on account of their frequent occurrence in nature; such as Parabolic Motion, Simple Harmonic Motion, Elliptic Motion. We propose to say a few words in explanation of each of these.

Parabolic Motion. The motion of a *projectile*, that is to say, of a body thrown in any direction and falling under the influence of gravity, was investigated by Galileo; and this is the first problem of Kinetics that was ever solved. We must confine ourselves here to a description of the motion, without considering the way in which it depends on the circumstance of the presence of the earth at a certain distance from the moving body. Galileo found that the path of such a body, or the curve which it traces out, is a parabola; a curve which may be described as the shadow of a circle cast on a horizontal table by a candle which is just level with the highest point of the circle.

It is convenient to consider separately the vertical and the horizontal motion, for in accordance with a law subsequently stated in a general form by Newton, these two take place in complete independence of one another. So far as its horizontal motion is concerned, the projectile moves uniformly, as if it were sliding on perfectly smooth ice; and, so far as its vertical motion is concerned, it moves as if it were falling down straight. The nature of this vertical motion may be described in two ways, each of which implies the other. First, a falling body moves faster and faster as it goes down; and the rate at which it is going at any moment is strictly proportional to the number of seconds which has elapsed since it started. Thus its downward velocity is continually being added to at a uniform rate. Secondly, the whole distance fallen from the starting-point is proportional to the *square* of the number of seconds elapsed; thus, in three seconds a body will fall nine times as far as it will fall in one second. The latter of these statements was experimentally proved by Galileo; not, however, in the case of bodies falling vertically, which move too quickly for the time to be conveniently measured, but in the case of bodies fall-

ing down inclined planes, the law of which he at first assumed, and afterwards proved to be identical with that of the other. The former statement, that the velocity increases uniformly, is directly tested by an apparatus known as Attwood's machine, consisting essentially of a pulley, over which a string is hung with equal weights attached to its ends. A small bar of metal is laid on one of the weights, which begins to descend and pull the other one up; after a measured time the bar is lifted off, and then, both sides pulling equally, the motion goes on at the rate which had been acquired at that instant. The distance travelled in one second is then measured, and gives the velocity; this is found to be proportional to the time of falling with the bar on.

The second statement, that the space passed over is proportional to the square of the number of seconds elapsed, is verified by Morin's machine, which consists of a vertical cylinder which revolves uniformly while a body falling down at the side marks it with a pencil. The curve thus described is a record of the distance the body had fallen at every moment of time.

Fluxions.

This investigation of Galileo's was in more than one aspect the foundation of dynamical science; but not the least important of these aspects is the proof that either of the two ways of stating the law of falling bodies involves the other. Given that the distance fallen is proportional to the square of the time, to show that the velocity is proportional to the time itself; this is a particular case of the problem. Given where a body is at every instant, to find how fast it is going at every instant. The solution of this problem was given by Newton's Method of Fluxions. When a quantity changes from time to time, its *rate* of change is called the *fluxion* of the quantity. In the case of a moving body the quantity to be considered is the distance which the body has travelled; the fluxion of this distance is the rate at which the body is going. Newton's method solves the problem, Given *how big* a quantity is at any time, to find its fluxion at any time. The method has been

called on the Continent, and lately also in England, the Differential Calculus; because the difference between two values of the varying quantity is mentioned in one of the processes that may be used for calculating its fluxion. The inverse problem, Given that the velocity is proportional to the time elapsed, to find the distance fallen, is a particular case of the general problem, Given how fast a body is going at every instant, to find where it is at any instant; or, Given the fluxion of a quantity, to find the quantity itself. The answer to this is given by Newton's Inverse Method of Fluxions; which is also called the Integral Calculus, because in one of the processes which may be used for calculating the quantity, it is regarded as a whole (integer) made up of a number of small parts. The method of Fluxions, then, or Differential and Integral Calculus, takes its start from Galileo's study of parabolic motion.

Harmonic Motion.

The ancients, regarding the circle as the most perfect of figures, believed that circular motion was not only *simple*, that is, not made up by putting together other motions, but also *perfect*, in the sense that when once set up in perfect bodies it would maintain itself without external interference. The moderns, who know nothing about perfection except as something to be aimed at, but never reached, in practical work, have been forced to reject both of these doctrines. The second of them, indeed, belongs to Kinetics, and will again be mentioned under that head. But as a matter of Kinematics it has been found necessary to treat the uniform motion of a point round a circle as compounded of two oscillations. To take again the example of a clock, the extreme point of the minute-hand describes a circle uniformly; but if we consider separately its vertical position and its horizontal position, we shall see that it not only oscillates up and down, but at the same time swings from side to side, each in the same period of one hour. If we suppose a button to move up and down in a slit between the figures XII. and VI., in such a way as to be always at the same height as the end of the minute-hand, this

button will have only one of the two oscillations which are combined in the motion of that point; and the other oscillation would be exhibited by a button constrained to move in a similar manner between the figures III. and IX., so as always to be either vertically above or vertically below the extreme point of the minute-hand. The laws of these two motions are identical, but they are so timed, that each is at its extreme position when the other is crossing the centre. An oscillation of this kind is called a *simple harmonic motion;* the name is due to Sir William Thomson, and was given on account of the intimate connection between the laws of such motions and the theory of vibrating strings. Indeed, the harmonic motion, simple or compound, is the most universal of all forms; it is exemplified not only in the motion of every particle of a vibrating solid, such as the string of a piano or violin, a tuning-fork, or the membrane of a drum, but in those minute excursions of particles of air which carry sound from one place to another, in the waves and tides of the sea, and in the amazingly rapid tremor of the luminiferous ether which, in its varying action on different bodies, makes itself known as light or radiant heat or chemical action. Simple harmonic motions differ from one another in three respects; in the extent or *amplitude* of the swing, which is measured by the distance from the middle point to either extreme; in the *period* or interval of time between two successive passages through an extreme position; and in the time of starting, or *epoch*, as it is called, which is named by saying what particular stage of the vibration was being executed at a certain instant of time. One of the most astonishing and fruitful theorems of mathematical science is this; that every *periodic* motion whatever, that is to say, every motion which exactly repeats itself again and again at definite intervals of time, is a compound of simple harmonic motions, whose periods are successively smaller and smaller aliquot parts of the original period, and whose amplitudes (after a certain number of them) are less and less as their periods are

more rapid. The "harmonic" tones of a string, which are always heard along with the fundamental tone, are a particular case of these constituents. The theorem was given by Fourier in connection with the flow of heat, but its applications are innumerable, and extend over the whole range of physical science.

The laws of combination of harmonic motions have been illustrated by some ingenious apparatus of Messrs. Tisley and Spiller, and by a machine invented by Mr. Donkin; but the most important practical application of these laws is to be found in Sir W. Thomson's Tidal Clock, and in a more elaborate machine which draws curves predicting the height of the tide at a given port for all times of the day and night with as much accuracy as can be obtained by direct observation. One special combination is worthy of notice. The union of a vertical vibration with a horizontal one of half the period gives rise to that figure of 8 which M. Marey has observed by his beautiful methods in the motion of the tip of a bird's or insect's wing.

Elliptic Motion.

The motion of the sun and moon relative to the earth was at first described by a combination of circular motions; and this was the immortal achievement of the Greek astronomers Hipparchus and Ptolemy. Indeed, in so far as these motions are periodic, it follows from Fourier's theorem mentioned above that this mode of description is mathematically sufficient to represent them; and astronomical tables are to this day calculated by a method which practically comes to the same thing. But this representation is not the simplest that can be found; it requires theoretically an infinite number of component motions, and gives no information about the way in which these are connected with one another. We owe to Kepler the accurate and complete description of planetary or elliptic motion. His investigations applied in the first instance to the orbit of the planet Mars about the sun, but it was found true of the orbits of all planets about the sun, and of the moon about the earth. The path of the moving body in each of these motions, is an ellipse, or oval shadow of a

circle, a curve having various properties in relation to two internal points or foci, which replace as it were the one centre of a circle. In the case of the ellipse described by a planet, the sun is in one of these foci; in the case of the moon, the earth is one focus. So much for the geometrical description of the motion. Kepler further observed that a line drawn from the sun to a planet, or from the earth to the moon, and supposed to move round with the moving body, would sweep out equal areas in equal times. These two laws, called Kepler's first and second laws, complete the kinematic description of elliptic motion; but to obtain formulæ fit for computation, it was necessary to calculate from these laws the various harmonic components of the motion to and from the sun, and round it; this calculation has much occupied the attention of mathematicians.

The laws of rotatory motion of rigid bodies are somewhat difficult to describe without mathematical symbols, but they are thoroughly known. Examples of them are given by the apparatus called a gyroscope, and the motion of the earth; and an application of the former to prove the nature of the latter, made by Foucault, is one of the most beautiful experiments belonging entirely to dynamics.

Rotation. Next in simplicity after the *translation* of a rigid body, come two kinds of motion which are at first sight very different, but between which a closer observation discovers very striking analogies. These are the motion of rotation about a fixed point, and the motion of sliding on a fixed plane. The first of these is most easily produced in practice by what is well known as a ball-and-socket joint; that is to say, a body ending in a portion of a spherical surface which can move about in a spherical cavity of the same size. The centre of the spherical surface is then a fixed point, and the motion is reduced to the sliding of one sphere inside another. In the same way, if we consider, for instance, the motion of a flat-iron on an ironing-board, we may see that this is not a pure translation, for the iron is frequently turned round as

well as carried about; but the motion may be described as the sliding of one plane upon another. Thus in each case the matter to be studied is the sliding of one surface on another which it exactly fits. For two surfaces to fit one another exactly, in all positions, they must be either both spheres of the same size, or both planes; and the latter case is really included under the former, for a plane may be regarded as a sphere whose radius has increased without limit. Thus, if a piece of ice be made to slide about on the frozen surface of a perfectly smooth pond, it is really rotating about a fixed point at the centre of the earth; for the frozen surface may be regarded as part of an enormous sphere, having that point for centre. And yet the motion cannot be practically distinguished from that of sliding on a plane.

In this latter case it is found that, excepting in the case of a pure translation, there is at every instant a certain point which is at rest, and about which as a centre the body is turning. This point is called the instantaneous centre of rotation; it travels about as the motion goes on, but at any instant its position is perfectly definite. From this fact follows a very important consequence; namely, that every possible motion of a plane sliding on a plane may be produced by the *rolling* of a curve in one plane upon a curve in the other. The point of contact of the two curves at any instant is the instantaneous centre at that instant. The problems to be considered in this subject are thus of two kinds: Given the curves of rolling to find the path described by any point of the moving plane; and, Given the paths described by *two* points of the moving plane (enough to determine the motion) to find the curves of rolling and the paths of all other points. An important case of the first problem is that in which one circle rolls on another, either inside or outside; the curves described by points in the moving plane are used for the teeth of wheels. To the second problem belongs the valuable and now rapidly increasing theory of *link-work*, which, starting from the wonderful discovery of an exact parallel motion by M. Peaucellier, has

received an immense and most unexpected development at the hands of Professor Sylvester, Mr. Hart, and Mr. A. B. Kempe.

Passing now to the spherical form of this motion, we find that the instantaneous centre of rotation (which is clearly equivalent to an instantaneous axis perpendicular to the plane) is replaced by an instantaneous axis passing through the common centre of the moving spheres. In the same way the rolling of one curve on another in the plane is replaced by the rolling of one *cone* upon another, the two cones having a common vertex at the same centre.

Analogous theorems have been proved for the most general motion of a rigid body. It was shown by M. Chasles that this is always similar to the motion of a corkscrew descending into a cork; that is to say, there is always a rotation about a certain instantaneous axis, combined with translation along this axis. The amount of translation per unit of rotation is called the *pitch* of the screw. The instantaneous screw moves about as the motion goes on, but at any given instant it is perfectly definite in position and pitch. And any motion whatever of a rigid body may be produced by the rolling and sliding of one surface on another, both surfaces being produced by the motion of straight lines. This crowning theorem in the geometry of motion is due to Professor Cayley. The laws of combination of screw motions have been investigated by Dr. Ball.

Thus, proceeding gradually from the more simple to the more complex, we have been able to describe every change in the position of a body. It remains only to describe changes of size and shape. Of these there are three kinds, but they are all included under the same name—*strains*. We may have, first, a change of size without any change of shape, a uniform dilatation or contraction of the whole body in all directions, such as happens to a sphere of metal when it is heated or cooled. Next, we may have an elongation or contraction in one direction only, all lines of this body pointing in this direction being increased or diminished in the same ratio; such as would happen to a rod six feet long

and an inch square, if it were stretched to seven feet long, still remaining an inch square. Thirdly, we may have a change of shape produced by the sliding of layers over one another, a mode of deformation which is easily produced in a pack of cards; this is called a *shear*. By appropriate combinations of these three, every change of size and shape may be produced; or we may even leave out the second element, and produce any strain whatever by a dilatation or contraction, and two shears.

Dynamics. We have already said that the change of motion of a body depends upon the position and state of surrounding bodies. To make this intelligible it will be necessary to notice a certain property of the three kinds of motion of a point which we described.

The combination of velocities may be understood from the case of a body carried in any sort of cart or vehicle in which it moves about. The whole velocity of the body is then compounded of the velocity of the vehicle and of its velocity relative to the vehicle. Thus, if a man walks across a railway carriage his whole velocity is compounded of the velocity of the railway carriage and of the velocity with which he walks across.

When the velocity of a body is changed by adding to it a velocity in the same direction or in the opposite direction, it is only altered in amount; but when a transverse velocity is compounded with it, a change of direction is produced. Thus, if a man walks fore and aft on a steamboat, he only travels a little faster or slower; but if he walks across from one side to the other, he slightly changes the direction in which he is moving.

Now, in the parabolic motion of a projectile, we found that while the horizontal velocity continues unchanged, the vertical velocity increases at a uniform rate. Such a body is having a downwards velocity continually poured into it, as it were. This gradual change of the velocity is called *acceleration;* we may say that the acceleration of a projectile is always the same, and is directed vertically downwards.

In a simple harmonic motion it is found that the acceleration is directed towards the centre, and is always proportional to the distance from it. In the case of elliptic motion it was proved by Newton that the acceleration is directed towards the focus, and is inversely proportional to the square of the distance from it.

Let us now consider the circumstances under which these motions take place. To produce a simple harmonic motion we may take a piece of elastic string, whose length is equal to the height of a smooth table; then fasten one end of the string to a bullet and the other end to the floor, having passed it through a hole in the table, so that the bullet just rests on the top of the hole when the string is unstretched. If the bullet be now pulled away from the hole so that the string is stretched, and then let go, it will oscillate to and fro on either side of the hole with a simple harmonic motion. The acceleration (or rate of change of velocity) is here proportional to the distance from the hole; that is, to the *amount of elongation of the string*. It is directed towards the hole; that is, in the direction of this elongation. In the case of the moon moving round the earth, the acceleration is directed towards the earth, and is inversely proportional to the square of the distance from the earth.

In both these cases, then, the change of velocity depends upon surrounding circumstances; but in the case of the bullet, this circumstance is the strained condition of an adjoining body, namely, the elastic string; while in the case of the moon the circumstance is the position of a distant body, namely, the earth. The motion of a projectile turns out to be only a special case of the motion of the moon; for the parabola which it describes may be regarded as one end of a very long ellipse, whose other end goes round the earth's centre.

There is a remarkable difference between the two cases. The swing of the bullet depends upon its size; a large bullet will oscillate more slowly than a small one. This leads us to modify the rule. If a large bullet is equivalent to two small ones, then

when it is going at the same rate it must contain twice as much motion as one of the small ones; or, as we now say, with the same velocity it has twice the *momentum*. Now the change of momentum is found to be the same for all bullets, when the momentum is reckoned as proportional to the quantity of matter in the bullet as well as to the velocity. The quantity of matter in a body is called its *mass;* for bodies of the same substance it is, of course, simply the quantity of that substance; but for bodies of different substances it is so reckoned as to make the rule hold good. The rule for this case may then be stated thus; the change of momentum of a body (that is, the change of velocity multiplied by the mass), depends on the state of strain of adjoining bodies. Regarded as so depending, this change of momentum is called the *pressure* or *tension* of the adjoining body, according to the nature of the strain; both of these are included in the name *stress*, introduced by Rankine.

But in the case of projectiles, the acceleration is found to be the same for all bodies at the same place; and this rule holds good in all cases of planetary motion. So that it seems as if the change of velocity, and not the change of momentum, depended upon the position of distant bodies. But this case is brought under the same rule as the other by supposing that the mass of the moving body is to be reckoned among the "circumstances." The change of momentum is in this case called the attraction of gravitation, and we say that the attraction is proportional to the mass of the attracted body. And this way of representing the facts is borne out by the electrical and magnetic attractions and repulsions, where the change of momentum depends on the position and state of the attracting thing, and upon the electric charge or the induced magnetism of the attracted thing.

Force, then, is of two kinds; the stress of a strained adjoining body, and the attraction or repulsion of a distant body. Attempts have been made with more or less success to explain each of these by means of the other. In common discourse the word "force"

means muscular effort exerted by the human frame. In this case the part of the human body which is in contact with the object to be moved is in a state of strain, and the force, dynamically considered, is of the first kind. But this state of strain is preceded and followed by nervous discharges, which are accompanied by the sensations of effort and of muscular strain; a complication of circumstances which does not occur in the action of inanimate bodies. What is common to the two cases is, that the change of momentum depends on the strain.

Having thus explained the law of Force, which is the foundation of Dynamics, we may consider the remaining laws of motion. It is convenient to state them first for particles, or bodies so small that we need take account only of their position. Every particle, then, has a rate of change of momentum due to the position or state of every other particle, whether adjoining it or distant from it. These are compounded together by the law of composition of velocities, and the result of the whole is the actual change of momentum of the particle. This statement, and the law of Force stated above, amount together to Newton's first and second laws of motion. His third law is, that the change of momentum in one particle, due to the position or state of another, is equal and opposite to the change of momentum in the other, due to the position or state of the first.

By the help of these laws D'Alembert showed how the motion of rigid bodies, or systems of particles, might be dealt with. It appears from his method that two stresses, acting on a rigid body, may be equivalent, in their effect on the body as a whole, to a single stress, whose direction and position will be totally independent of the shape and nature of the body considered. The law of combination of stresses acting on a system of particles is, in fact, the same as the law of combination of velocities, so far as regards the motion of the system as a whole. This beautiful but somewhat complex result of Dynamics has been used in some text-books as the independent foundation of Statics, under the

name of the parallelogram of forces; a singular inversion of the historical order and of the methods of the great writers.

When the result of all the circumstances surrounding a body is that there is no change of momentum, the body is said to be in equilibrium. In this case, if the body is at rest, it will remain so; and on this account the study of such conditions is called Statics. In dealing with the statics of rigid bodies, we have only to examine those cases in which the resultant of the external stresses and attractions acting on the body amounts to nothing. But the most important part of statics is that which finds the stresses acting in the interior of bodies between contiguous parts of them; for upon this depends the determination of the requisite strength of structures which have to bear given loads. It is found that the way in which the stress due to a given strain depends on the strain, varies according to the physical nature of the body; for bodies, however, which are not crystalline or fibrous, but which have the same properties in all directions, there are two quantities which, if known, will enable us always to calculate the stress due to a given strain. These are, the elasticity of volume, or resistance to change of size; and the rigidity, elasticity of figure, or resistance to change of shape. Problems relating to the interior state of bodies are far more difficult than those which regard them as rigid. Thus, if a beam is supported at its two ends, it is very easy to find the portion of its weight which is borne by each support; but the determination of the state of stress in the interior is a problem of great complexity.

There is one theorem of kinetics which must be mentioned here. If we multiply half the momentum of every particle of a body by its velocity, and add all the results together, we shall get what is called the kinetic energy of the body. When the body is moved from one position to another, if we multiply each force acting on it—whether attraction or stress—by the distance moved in the direction opposite to the force, and add the results, we shall get what is called the work done against the forces during the change

of position. It does not at all depend on the rate at which the change is made, but only on the two positions. If a body moves, and loses kinetic energy, it does an amount of work equal to the kinetic energy lost. If it gains kinetic energy, an amount of work equal to this gain must be done to take it back from the new position to the old one. The amount of work which must be done to take a body from a certain standard position to the position which it has at present is called the potential energy of the body. The theorem may be stated in this form; the sum of the potential and kinetic energies is always the same, provided the surrounding circumstances do not alter. Hence the theorem is called the Conservation of Energy. It is one fact out of many that may be deduced from the equations of motion; it is not sufficient to determine the motion of a body, but it is exceedingly useful as giving a general result in cases where it might be difficult or undesirable to investigate all the particulars; and it is especially applicable to machines, the important question in regard to which is the amount of work which they can do.

It will have been seen that the science of motion depends on a few fundamental principles which are easily verified, and consists almost entirely of mathematical deductions and calculations based on those principles. It is no longer therefore an experimental science in the same sense as those are in which the fundamental facts are still being discovered. The apparatus connected with it may be conveniently classified under three heads:—

(*a*) Apparatus for illustrating theorems or solving problems of kinematics, such as those mentioned above for compounding harmonic motions. There is reason to hope for great extension of our powers in this direction.

(*b*) Apparatus for measuring the dynamical quantities, such as weight, work, and the elasticities of different substances. These are more fully classified under Measurements.

(*c*) Apparatus designed for purposes belonging to other sciences, but illustrating by its structure and functions the results of kinematics or dynamics. In this class the remainder of the Collection is included.

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MOLECULAR PHYSICS.

I.—General Considerations.

The properties of matter which is not associated with life may, in the present condition of those of the exact Sciences which are founded mainly on experiment, be imperfectly divided into (1) Chemical, (2) Physical, and (3) Molecular.

(1.) The faculty which the elements possess of combining in definite weight-ratio, gives sameness to the bodies which form the earth: the fact that this ratio is always the same under identical conditions, and often the same under widely different conditions, gives them stability. It is radiation, acting either directly, or through the instrumentality of its offspring, life, which is the main instrument which disturbs the otherwise stable equilibrium of the chemical forces.

(2.) The faculty which substances have of being the vehicles or temporary abodes of physical forces, may be considered as giving rise to the physical attributes of matter in the more limited sense. These are exhibited in the transmission of pressure in machines, the assumption of mechanical vibration, the electric and magnetic excitement, the absorption and transmission of radiation, and the acquirement of weight when mass is near to mass. The bodies concerned are ponderable. The forces act, or may act, between bodies which are not in direct mechanical contact. Such states and changes are referred to the action of physical forces, which are, therefore, neither more nor less numerous than are the kinds of change which bodies are competent to suffer. The tendency

now clearly manifests itself to consider the various physical forces as being all varieties of the mechanical force, differing from one another in method of application and in their effects upon the nature of the bodies on which they act. The thrust through a stick, the blow of a wave of sound, the attraction of a magnet, the push of a gas when expanded by heat, are all mechanical forces, and, therefore, it is argued with much reason, mechanical force must be in activity in the space between the active and passive body. Hence the general conception that the force which holds together the parts of a bar of steel is due to the same cause as that which urges the bar to the ground, as that which forces it towards a magnet, and as that which causes it to rust in moist air.

From the fact that, under like conditions, chemical union occurs in constant weight-ratio, arose the first modern conception of atoms as being indivisible, invisibly small, presumably spherical, masses of the elements. It was concluded that each of the atoms of which one and the same element consists has the same weight, and that the atoms of other elements have all other different weights; and that the weight-ratio of chemical combinations is compounded of the weight-ratio of the elementary atoms, and of their relative number. According to the atomic theory, the uniformity of composition of the body water, every nine pounds of which consists of one pound of hydrogen and eight pounds of oxygen, depends upon (*a*) the fact that when water is formed every atom of oxygen unites with one atom of hydrogen, joined with the fact that the oxygen atom is eight times as heavy as the hydrogen; or (*b*) that each atom of oxygen unites with two atoms of hydrogen, joined with the fact that the atom of oxygen is sixteen times as heavy as that of hydrogen. Such a hypothetical group of atoms is called a molecule, and it is generally supposed that such molecules may, without undergoing internal derangement, act like atoms in combining with atoms or other molecules. It has been maintained by some that the atoms in an element are never free, but that they are grouped together or combined as molecules,

and accordingly chemical combination is then regarded as resulting from the double recomposition of two elemental molecules. Further, it is maintained that the atomic combinations in one and the same element may be, and in many cases are, numerous in kind according to condition, and that, especially, variation in heat intensity, which is supposed to be intermolecular commotion, is competent to determine the numerical aggregation of the atoms constituting the molecule. This notion has been offered to explain the fact that the degree of refrangibility of the light which is absorbed by the vapour of an element depends upon its temperature, and the belief that the stratification of the sun's chromosphere and reversing layer is not in accord with the densities of its constituents, under the supposition that the ordinary law of the expansion of vapours by heat holds good. That such atomic aggregation when once effected may be very permanent is shown by the allotropism so frequent among the non-metallic elements.

After the atomic theory was adopted to satisfy the supposed requirements of chemistry, it became, in an extended form, prolific as a means of interpreting the action of other forces. The fact that the expenditure of a given amount of work in overcoming friction always gives rise to the same amount of heat, and the observation that more heat must enter a given volume of a gas at a given temperature to heat it through a given range of temperature when the gas expands and thrusts back the atmosphere, than when it is protected by a rigid shell, led to the notion that heat is the blow given by a moving atom or molecule, and that the force of the blow depends upon the mass of the molecule and its velocity. In heat-tension or temperature the velocity only is concerned, in heat quantity the mass also. The elastic force of air is thus viewed as the sum of the atomic or molecular blows given to the enclosing vessel. Further, the spread of heat by conduction is viewed as being due to the occasional impact of the more rapidly moving atoms or molecules of the hotter upon the more slowly moving ones of the less hot. From the rate at which a gas enters

a vacuum the rate of molecular motion is deduced. From the rate of diffusion of two gases the frequency of impact is derived. Thereon is based the attempt to determine within limits the size of atoms.

The hypothetical medium ether is supposed generally to be continuous through otherwise empty space, and through matter, or, at all events, through intermolecular space. Imponderable in the ordinary sense, it must, if it be continuous, be elastic and competent to convey the enormous mechanical force involved in stellar radiation. If elasticity of continuous matter be inadmissible, then ether itself must be atomic and convey force by its own interatomic impacts. The thrust which radiation through the most perfect artificial vacua is said to give to matter may, if it be due directly to radiation, be attributed to such blows.

(3.) Holding a place somewhat between the energetic, abrupt, and character-changing chemical phenomena and those of heat, light and electricity are the innumerable and ill-classified phenomena of what is more restrictedly called molecular physics; such are condition of structure or texture, cohesion and adhesion, mixture, and the more palpable phases of intermolecular motion.

Soon following on the acceptance of the atomic hypothesis was the endeavour to deduce the outward form of crystals from the supposed arrangements of their stationary atoms and molecules. The doctrine of isomorphism taught what elements and compounds could replace one another in crystalline bodies without affecting their geometric character. The conception of the internal motion of the atoms appears for a time to have considerably turned aside the current of thought from this direction, perhaps to be resumed should a clue be got to the shape of the polygonal atomic paths. The study of solids as distinguished from liquids, as well as that of liquids as apart from gases, has been checked by the discovery of the continuity which exists between liquids and their vapours under great pressure and the alteration of the temperature at which solidification ensues when a liquid is

under strain. The continuity of the so-called three forms of matter, Solid, Liquid, and Gaseous, is supported by the observation that while both solids and liquids have cohesion, both liquids and gases have viscosity, and all three have volume elasticity. While the cohesion of solids is measured directly by their resistance to rupture, that of liquids may be determined either in the same way or by the size of a drop, which on reaching a certain stage of its growth detaches itself from its root, or indirectly by pitting liquid cohesion and gravity against the adhesion between the liquid and a solid in a capillary tube. The viscosity of liquids and gases, that is, their resistance to intermolecular disturbance, is manifested by the obstruction they offer to solids moving through them. And this effect is, in the case of liquids, complicated by the adhesion between the solid and liquid. The transpiration of gases through narrow tubes, and the flow of liquids through them, are also conditioned by, and consequently measure, fluid viscosity.

The intermolecular motion of a single fluid apart from the purely hypothetical heat agitation is exhibited in sound waves or travelling variations in density. Here the molecule moves only in a straight line passing through the origin of commotion. And in such molecular motion the only variation in one and the same fluid appears to be (1) wave length or distance between points in homologous phase; (2) wave amplitude, or length of molecular excursion; and (3) probably wave quality, or kind of variation in density between neighbouring homologous points. Since sound waves of all amplitudes travel nearly at the same rate the frequency of recurrence of wave impact at a point at a constant distance from the wave source—the audible pitch—is a measure of the wave length; while the loudness is the physiological measure of the wave amplitude. The total density of a mass of air receiving and transmitting sound waves is less than when it is at rest, and there is accordingly a tendency of bodies which obstruct the wave system to approach the source of sound.

More various in kind are the systematic and sequential mole-

cular movements in liquids which give rise to liquid waves. When unchecked, the vertical displacement of a part of a liquid at the surface results in travelling annular elevations and depressions. But here the wave is the sum of the motions of the individual molecules in orbits, which lie in vertical planes in the direction of propagation. Amplitude and wave length have now both an effect upon wave rate, the second directly influencing it and the first indirectly, because in a boundless liquid the amplitude is partly convertible into length. In confined spaces, the reflected waves may so meet the advancing ones that nodes ensue and stationary waves are established which are constant in wave length. Whatever be the amplitude of such waves, their periods are the same, and the rate of wave progression varies as the square root of the wave length and the wave period is, in the case of a circular vessel in which there is one nodal ring, the same as that of a pendulum whose length is equal to the radius of the vessel.

In the cases of intermolecular motion between unlike bodies or mixtures, we may, for the sake of classification, consider matter in its three forms, solid, liquid, and gaseous. Between solids and solids molecular motion ensues, in the process of cementation of carbonation of iron, where the one element penetrates the other without either being liquefied. Here, indeed, there may be various stages of carbonation, reaching from the carbon on one side to the iron on the other, and any intermediate molecule may be receiving carbon from the one side and giving it to the other. Yet mineralogy furnishes many unquestionable examples of the penetration of one kind of solid matter through another without fusion or solution. The true molecular penetration of a liquid into a solid is also not infrequent, witness the absorption of water by gelatin, a phenomenon quite distinct from the absorption of a liquid into a porous body, which is a case of capillarity. The entrance into a solid of a vapour or gas furnishes the cases of occlusion, in which iron, palladium, and other metals absorb many times their own volume of hydrogen. To occlusion may probably

be referred the absorption of oxygen by metallic silver, although while occluded hydrogen is expelled by heat, occluded oxygen escapes as the metal cools, or at least as it solidifies. The formation of ammonium amalgam can scarcely be classed with the above, because the volume of the metal is so notably increased, and its metallic aspect, when saturated with the hydrogen-ammonia, is so impaired.

The passage of a solid into a liquid is due to the overcoming of the cohesion of the solid, in the first instance, by the adhesion of the liquid to it, and afterwards by that of the solution. While all gases or vapours intermix with one another in all proportions, the mixture between liquids and liquids sometimes takes place in all proportions, and is sometimes limited in quantity, so that any less, but no greater quantity than n of liquid A will dissolve in m of B. And the same limitation always holds when solids dissolve in liquids. This ratio of solubility cannot at present be deduced from the elementary composition of the substances, but it may be broadly laid down that bodies the most similar in elementary composition mix the most abundantly. A liquid rich in carbon will, for instance, dissolve a great many solids containing that element in combination. Water dissolves most abundantly those alcohols which stand nearest to it in composition. The solubility of a solid in a liquid is always increased by heat, except where the heat determines the formation of some new and less soluble body.

The solubility of a crystalline salt in water extends below the freezing-point of water, and accordingly, as a solution of a salt saturated above the freezing-point is cooled, the salt or some hydrate separates in larger and larger quantity until a certain temperature below the freezing-point of water is reached, when the remainder of the salt and the water solidify together at a constant temperature and in a fixed ratio. The temperature is that which results from the use of the same salt with ice as a freezing mixture, and the ratio between the salt and the water in the solid formed is the same as in the liquid part of such a freezing mixture. On

the other hand, on cooling a very weak solution of a salt ice only separates, and this continues with lowering temperature until the same ratio and the same temperature as before are reached, whereupon the salt and the water solidify in union. In this sense water at its freezing temperature may be viewed as a saturated solution of ice in water. Water at its maximum density is still simple water. At temperatures between those of its maximum density and its freezing-point, it is a solution of ice, and hence its diminished density.

Although the quantity of a crystalline solid which a liquid holds in solution increases with the temperature, yet on cooling a warm saturated solution it often occurs that no solidification ensues unless some nucleus or foreign substance affords a point from which the crystallization may commence. Such a solution is super-saturated, and such super-saturation may take place simultaneously in regard to two or more of the solid constituents of a solution.

The gradual automatic diffusion of a salt through water above it may be viewed either as a motion of the molecules of the salt amongst those of the solution above them until they reach the water; or, as a differential motion of the charged water itself: when such diffusion occurs through permeable walls, it is called osmose. There is in most cases an interchange of liquid through the wall, and the less dense exceeds the more dense in its osmotic quantity. The nature of the porous wall is discriminating in regard to the components of a solution in the sense of determining which it shall let pass. A membrane such as parchment being in contact with water on the one side, and a solution of gum and chloride of sodium on the other, will separate the salt from the gum, letting the former pass through, and retaining the gum further diluted by water passing in the opposite direction. Such separation is called dialysis. By its means various bodies before unknown in purely aqueous solution have been procured; such as soluble alumina by diffusing away hydrochloric acid from a solution of the chloride of

aluminium in water. The bodies which pass through such a septum are called crystalloid, those retained are colloid, the wall in this case being colloid. Colloid bodies when solid are amorphous.

The energy of diffusion of a solid into a gas, and that of a liquid into a gas or vacuum is usually measured by the vapour tension, or thrust which the vapour of the solid or liquid exerts, as exhibited by the depression of the barometric column when the body is introduced into a partial or perfect vacuum. The vapour tension so measured always increases with the temperature, and is the same with whatever gas the vacuum may be partially filled. But the vapour tension does not measure directly the rate at which vaporisation takes place, when a continually renewed current of a gas sweeps over a vaporisable solid or liquid. Here the relative natures of the gas and body are concerned. Thus alcohol evaporates more rapidly under like conditions in a current of olefiant gas than in one of air; and the difference depends upon the relative ratio of solubility of the gas in the liquid. Moreover, while the vapour tension of water is continuous through its maximum density, the evaporation shows a tendency to diminish at that point, overwhelmed, but not obliterated by the temperature.

The liquefaction of a gas by absorption into a liquid is also conditioned by their relative chemical natures, as well as by the common pressure and temperature. The solubility increases with the pressure, and unless chemical union between the gas and the liquid ensues, the solubility of the gas in the liquid runs parallel with the evaporation of the liquid into the gas.

The diffusion of a gas into a gas when they are in direct contact with one another is almost immeasurably rapid, but when separated by a permeable septum a diffusion ensues similar to that between liquids. The less dense gas moves through the wall with the greater nimbleness, and this difference of rate may give rise to great force.

FREDERICK GUTHRIE.

II.—Instruments connected with Fluids.

In countries where the fertility of the soil is capable of being greatly increased by artificial irrigation, the attention of all ingenious persons is naturally directed to devising means whereby the labour of raising water may be diminished. Hence we find that in China and in India, but especially in Egypt, great progress was made in the art of producing and guiding the motion of water.

The first pump worked by a piston of which we have any account seems to be that invented by Ctesibius of Alexandria, about 130 B.C.

The construction of this pump, as described by Vitruvius, resembles that of the modern fire-engine. It had two barrels, which discharged the water alternately into a closed vessel, the upper part of which contained air. This air-chamber acted as a reservoir of energy, and equalised the pressure under which the water was emitted from the discharge pipe.

Hero, a scholar of Ctesibius, invented a number of ingenious machines. He delighted in curious combinations of siphons, by which fountains were made to play under unusual circumstances. We should call such machines toys, but though to us they have no longer any scientific value, we must regard them as among the first instances of apparatus constructed not in order to minister directly to man's necessities or luxuries, but to excite or to satisfy his curiosity with respect to the more unusual phenomena of nature.

From the time of Ctesibius and Hero to that of Galileo (1600) pumps were constructed chiefly for useful, as distinguished from scientific, purposes, and considerable skill was developed in the art of forming the barrel and piston so as to work with a certain degree of accuracy.

Galileo showed that the reason why water ascends in a sucking pump is not that Nature abhors a vacuum, but that the pressure of the atmosphere acts on the free surface of the water, and that this pressure will force the water only to a height of 34 feet; for

when this height is reached, the water rises no further, and this shows either that the pressure of the atmosphere is balanced by that of the column of water, or else that Nature has become reconciled to a vacuum.

From this time the production of a vacuum became the scientific object aimed at by a great number of inventors. Torricelli, the pupil of Galileo, in 1642, made the greatest step in this direction, by filling with mercury a tube closed at one end and then inverting the tube with its open end in a vessel of mercury. If the tube was long enough the mercury fell, leaving an empty space at the top of the tube. The vacuum obtained by filling a vessel with mercury and removing the mercury without admitting any other matter is hence called the Torricellian vacuum. Torricelli, therefore, gave us at once the mercury-pump and the barometer, though the subsequent history of these two instruments is very different.

A little before 1654 Otto Von Guericke, of Magdeburg, first applied the principle of the common pump to the production of a vacuum. The fitting of the pistons of the pumps of those days, however, though sufficiently water-tight, was by no means air-tight. He therefore began by filling a vessel with water and then removing the water by a water-pump. In his experiments he met with many failures, but he continued to improve his apparatus till he could not only exhibit most of the phenomena now shown in exhausted receivers, but till he had discovered the reason of the imperfection of the vacuum when water was used to keep the pump air-tight.

"In the year 1658 Hooke finished an air-pump for Boyle, in whose laboratory he was an assistant; it was more convenient than Guericke's, but the vacuum was not so perfect; yet Boyle's numerous and judicious experiments gave to the exhausted receiver of the air-pump the name of the Boylean vacuum, by which it was long known in the greatest part of Europe. Hooke's air-pump had two barrels, and with some improvements by

Hauksbee it remained in use until the introduction of Smeaton's pump, which, however, has not wholly superseded it."*

The history of the air-pump after this time relates chiefly to the contrivances for insuring the working of the valves when the pressure of the remaining air is no longer sufficient to effect it, and to methods of rendering the working parts air-tight without introducing substances the vapour of which would continue to fill the otherwise empty space.

There is one form of air-pump, however, which we must notice, as in it all packing and lubricating substances are dispensed with. This is the air-pump constructed by M. Deleuil, of Paris,† in which the pistons are solid cylinders of considerable length, and are not made to fit tightly in the barrels of the pump. No grease or lubricating substance is used, and the pistons work easily and smoothly in the barrels. The space between the piston and the barrel contains air, but the internal friction of the air in this narrow space is so great that the rate at which it leaks into the exhausted part of the barrel is not comparable with the rate at which the pump is exhausting the air from the receiver. It has been shown by the present writer that the internal friction of air is not diminished even when its density is greatly reduced. It is for this reason that this pump works satisfactorily up to a very considerable degree of exhaustion.

Pumps of the type already described are still used for the rapid exhaustion of large vessels, but since the physical properties of extremely rarefied gases have become the object of scientific research, the original method of Torricelli has been revived under various forms.

Thus we have one set of mercury-pumps in which the mercury is alternately made to fill a certain chamber completely and to drive out whatever gas may be in it, and then to flow back leaving the chamber empty.

* Thomas Young's Lectures on Nat. Phil. (1807). Lecture xxx.
† Comptes Rendus, t. lx. p. 571. Carl's Repertorium.

Sprengel's pump is the type of the other set. The working part is a vertical glass tube longer than the height of the barometer, and so narrow that a small portion of mercury placed in it is compelled by its surface-tension to fill the whole section of the tube. The mercury is introduced into this tube from a funnel at the top through a small India-rubber tube regulated by a pinch-cock, so that the mercury falls in small detached portions, each of which drives before it any air which may be in the tube till it escapes into a mercury-trough, into which the bottom of the tube dips.

The vessel to be exhausted is connected to a tube which enters at the side of the vertical tube near the top. Any air or other gas which may be in the vessel expands into the vacuum left in the vertical tube between successive portions of the falling mercury, and is driven down the tube by the next portion of mercury into the mercury-trough, where it may be collected.

As long as the rarefaction of the air is not very great the quantity of air which is included between successive portions of mercury is sufficient to act as a sort of buffer, but as the rarefaction increases the portions of mercury come together more abruptly, and produce a sound which becomes sharper as the vacuum becomes more perfect.

After the mercury-pump has been in action for some hours the quantity of matter remaining in the vessel is very small. If the tubes have been joined by means of caoutchouc connections there is a trace of gaseous matter emitted by the caoutchouc. It is therefore necessary, when a very perfect vacuum is desired, to make all the joints "hermetical" by fusing the glass. Still, however, there remains a trace of matter. The vapour of mercury is, of course, present, and the sides of the glass vessel retain water very strongly, and part with it very slowly, when all other matter is removed.

By passing a little strong sulphuric acid through the pump along with the mercury, vapours both of mercury and of water may be in great measure removed.

MM. Kundt and Warburg have got rid of an additional quantity of water-substance by heating the vessel to as high a temperature as the glass will bear while the pump was kept in action.

A method which has been long in use for getting a good vacuum is to place in the vessel a stick of fused potash, and to fill it with carbonic acid, and, after exhausting as much as possible, to seal up the vessel. The potash is then heated, and when it has again become cold, most of the remaining carbonic acid has combined with the potash.

Another method, employed by Professor Dewar, is to place in a compartment of the vessel a piece of freshly heated cocoa-nut charcoal, and to heat it strongly during the last stages of the exhaustion by the mercury-pump. The vessel is then sealed up, and as the charcoal cools it absorbs a very large proportion of the gases remaining in the vessel.

The interior of the vessel, after exhaustion, is found to be possessed of very remarkable properties.

One of these properties furnishes a convenient test of the completeness of the exhaustion. The vessel is provided with two metallic electrodes, the ends of which within the vessel are within a quarter of an inch of each other. When the vessel contains air at the ordinary pressure a considerable electromotive force is required to produce an electric discharge across this interval. As the exhaustion proceeds the resistance to the discharge diminishes till the pressure is reduced to that of about a millimetre of mercury. When, however, the exhaustion is made very perfect the discharge cannot be made to take place between the electrodes within the vessel, and the spark actually passes through several inches of air outside the vessel before it will leap the small interval in the empty vessel. A vacuum, therefore, is a stronger insulator of electricity than any other medium.

MM. Kundt and Warburg have experimented on the viscosity of the air remaining after exhaustion, and on its conductivity for heat. They find that it is only when the exhaustion is very per-

fect that the viscosity and conductivity begin sensibly to diminish, even when the stratum of the medium experimented on is very thin.

But the most remarkable phenomenon hitherto observed in an empty space is that discovered by Mr. Crookes. A light body is delicately suspended in an exhausted vessel, and the radiation from the sun, or any other source of light or heat, is allowed to fall on it. The body is apparently repelled and moves away from the side on which the radiation falls.

This action is the more energetic the greater the perfection of the vacuum. When the pressure amounts to a millimetre or two the repulsion becomes very feeble, and at greater pressures an apparent attraction takes place, which, however, cannot be compared either in regularity or in intensity to the repulsion in a good vacuum.

From these instances we may see what important scientific discoveries may be looked for in consequence of improvements in the methods of obtaining a vacuum.

J. CLERK MAXWELL.

ACOUSTICAL INSTRUMENTS.

Sound, from a physical point of view, may be defined as vibration appreciable to the ear. It appears, at its lower limit, to be continuous with vibration as detectable by common tactile sensation; hence its exact musical commencement is rather indefinite. It is usually given at thirty-two single or sixteen double vibrations per second. Apparatus for the demonstration of this fact will be noted farther on. Its higher limit is even more variable, owing to physiological differences between different ears; but 73,000 single or 36,500 double vibrations per second probably represent the highest note ever heard. Two organ pipes are exhibited, the individual sound of which is, for this reason, inaudible, but whose resultant tone is within the limits of hearing.

The line of demarcation between mere noise and musical sound seems similarly vague. Dr. Haughton has ingeniously shown that the rattling of vehicles over equal-sized stones becomes musical at a definite velocity; from the confused rattle of a railway train in a tunnel the practised ear can disentangle and, as it were, mentally sift out grand organ-harmonies; and a falling plank in the Crystal Palace gives musical notes by periodic re-percussion at equal intervals. On the other side, castanets, tomtoms, side-drums, triangles, cymbals, all instruments of music proper, only give noise similar to the guns added in Russia to Italian music, or the hundred anvils "played on" at the Boston Celebration. Even

Beethoven, in his grandest symphony, sounds every note of the scale at once with musical effect.

The present remarks are mainly concerned with instrumental appliances which minister to sound. The physical aspect of acoustics has been lucidly laid down in the introductory notice. To bridge over the gap between this science and the art of music slightly more extended treatment is needed; for instance, besides—

1.—Its modes of production.

2.— „ „ propagation.

3.— „ „ „ determination and measurement.

4.—An important consideration must be the history and ethnological variation of musical sound; nor can we omit (5) the various schemes of temperament and tuning, or the effects of heat on sounding bodies. Lastly—

6.—Special applications to music must be included in the list.

1.—The modes of production may best be considered under definite types, such as the following:—

Springs or rods.—Jew's-harp, "nail-fiddle," musical-box, tuning-fork, clock-gongs of wire, Wheatstone's resonating-tube.

Bells.—Spherical or irregular in shape, musical glasses.

Plates.—Steel, glass, stone, and wood, harmonicons, gongs, and Burmese bells, Indian instruments.

Strings.—Plucked, hammered, bowed, excited by wind, straight strings, simple or loaded, coiled spiral strings. Sustaining the sound of rods or strings by means of electricity, wind, or vibrating percussion.

Membranes.—Kettle-drums, &c.

Pipes.—Organ-pipes, wood, metal, reed.

Reeds.—Free, beating, compounded with strings or springs.

Musical flames.—Pyrophone.

2.—Modes of propagation may be studied, as—

Air.—Speaking-tubes, speaking trumpets, bells of wind instruments, velocity experiments, reinforcement-consonance in resonators, consonant vessels, as in Indian instruments and in Greek theatres.

Metal.—Wires, destruction of echo by interference

Wood.—Telephone.

3.—The determination and measurement of sound may be accomplished by Savart's wheel, Sirens, Optical and Graphical methods, by Beats and Interferences.

4.—Its history and ethnology from ancient instruments and their reproduction, Egyptian pipes, hydraulic organs, Oriental and national instruments.

5.—Temperaments, &c. Perronet Thompson's inventions, Ellis's duodenes, Bosanquet's harmonium. Effects of Heat and Electricity.

6.—Special applications to music. Discoveries as to timbre or quality.

Physiological Aspect of Acoustics.

The audibility of acute sounds has been noticed above. Very elaborate apparatus is exhibited for determining the lower limit of musical character. Professor Helmholtz's experiments being made with a thin string, loaded with a copper coin, offered slight power of consonance or reinforcement, and the tone consequently soon faded out. In Messrs. Elliot's instrument, and in the four-string double-bass shown, better conditions of sympathetic vibration being afforded, and a larger mass of air being set in vibration, notes considerably lower in the scale were produced with musical character.

The perception of distinction, harmony, discord, and of melodious succession, appear to be in great measure due to acquirement, aided by natural sensitiveness of ear in the learner.

1. *Modes of production* are almost innumerable, if every variety be included.

Among the class of springs or rods the nail-fiddle seems the simplest. A circle of metal vibrators, each of which speaks to a certain note, is here touched by a bow, or even plucked by the finger. In the musical-box these vibrators are arranged in a long comb, being weighted on their underside and plucked by steel pins inserted into a rotating barrel kept in motion by clockwork and regulated by a fly. In the Jew's-harp the controlling power over the note is the volume of air in the cavity of the mouth, the lax "reed" or spring of the instrument being capable of responding to very different rapidities of vibration.

In tuning-forks, the necessity for firmly fixing the base of the rod or spring is obviated by attaching it to a second similar rod or spring, which vibrates in opposition, and keeps the whole mass in equilibrium. An instrument with single springs struck by hammers, and furnished with a key-board, is made by Messrs. Cramer and Co.

The wire gongs of American and other clocks are coiled into a flat spiral, attached to a heavy mass of metal at the outer end, and firmly screwed to the wood of the case; being struck by a hammer close to the fixed end, they produce very profound complex notes, much resembling those of a large church-bell.

Plates are illustrated by various instruments commonly called harmonicons, which may be made of wood, glass, steel, or even of compact stone. Many Oriental instruments are formed out of the first material, usually the outer silicious layer of the bamboo, and are remarkable for the presence of resonators reinforcing the note, which will be adverted to farther on. The amount of tone is astonishingly large and pure. Such an instrument, under the name of the "Xylophone," has recently been produced at many London concerts. Another, made of crystalline slate in bars, termed the "rock harmonicon," was exhibited a few years back. Mozart writes for a like instrument, probably made of steel, in his *Flauto Magico*, where it is supposed to imitate the sounds of the

sistrum, with which Papageno is entrusted. A remarkable instance of a large vibrating plate of metal is the so-called Chinese "bell" which is exhibited.

Bells proper are usually in the form of vessels either of hemispherical shape, as in clock-bells, or of a very complex outline, as in church and house-bells.

The musical-glasses, formerly in great repute, and recently revived, were a collection of glass vessels selected so as to form an approximate scale, and further tuned by pouring in water. Their note was excited by rubbing the free edge, either with the moistened finger, or with a wetted cloth. An ingenious modification of this arrangement is shown, wherein the bells are fixed to a rotating spindle, and touched while in rotation with a wetted excitor. The sounds thus obtained are continuous, and of peculiarly luscious, though cloying quality.

Strings embrace too many varieties for full discussion. The chief novelties exhibited are the flattened spiral strings described farther on, and the heavily covered string attached to a double bass, from which the sixteen-foot C can be produced without unwieldly increase of length.

The use of strings formed of an open coil has been before attempted, but without success, the coil being unable to withstand the necessary strain. This difficulty has been overcome by Mr. Baillie Hamilton, who has invented a process of rolling and tempering steel wire into a form such that the coil has enormous power of resistance to any strain that can be applied to a pianoforte string. Moreover, as the strain on every coil is chiefly lateral, the tension is that of a spring, and is not greatly affected by the causes which derange the pitch of ordinary strings. It is needless to point out the advantage of gaining more than the length of a grand pianoforte string in the space occupied by that of a small upright instrument.

Pipes and reeds present the same difficulty; the former, however, in their various forms, are shown; and the latter, as "free reeds," form the foundation of the "seraphine," harmonium, and American organ principle. Their "beating" modifications are to be seen in the organ, and in several orchestral instruments, such as the clarionet.

Membranes are chiefly met with in the form of drums, of which three varieties—the side drum, the bass drum, and kettle-drum—are in use. The first speaks a high, but undefined, note, the penetrating power of which is enhanced by the "snare," a loop of catgut stretched tightly across the lower membrane. The bass drum gives a similarly undefined, but extremely low, note. Both act chiefly in marking time and accent. The kettle-drum used in orchestras is a more strictly musical instrument than the two former. It gives a definite note of 8 or 16 foot tone. Two tuned to the tonic and dominant of the scale, or exceptionally to some other interval, are commonly employed, but a larger number is occasionally used with effect. Berlioz proposed to extend their employment, and in one of his works, the "Requiem," writes for a chromatic octave of twelve, tuned in semitones.

Modes of propagation in Air were studied by a French Commission in 1822. The observers were divided into two groups, placed respectively at Mont Lhéry and at Villejuif, and twelve alternate cannon shots were fired from each station. By measuring the interval between the appearance of the flash and the arrival of the sound, the rapidity of the latter was fixed, for 16° C., at 340·9 metres per second.

In Water, Colladon and Sturm made excellent observations on the Lake of Geneva. The sound was produced by the stroke of a hammer on a submerged bell, some gunpowder being at the same instant ignited. It was received by a kind of speaking trumpet, shown in the Exhibition, the bell being covered by a sheet of metal. The distance between the two stations, 13,487

metres, was traversed in 9·25 seconds, giving 1,435 metres per second as the velocity in water at 8° C.

In an Iron Pipe it was found by Biot to be 3,250 metres per second.

In Wood its transmission was ingeniously demonstrated by Wheatstone. His telephone consisted of long rods of light pine affixed in a lower room to various instruments. On a resonant body being attached to the upper end of the rods in an upper chamber, not only the pitch, but even the quality, of the various tones was distinctly reproduced.

The transmitting power of wood is daily used in the stethoscope for medical purposes.

Under this heading may be named the reinforcement produced by bells, or trumpet-like expansions seen at the lower end of many instruments; by the speaking trumpet on the voice; the effects of consonance in soundboards; in the bamboo harmonicon already named; and in the hollow vessels said to have been used in Greek theatres to increase the resonance of the actor's voice. In the measured and monotonic recitation of Greek tragedy, no doubt the result may have been favourable; though in the inflected diversities of modern speaking it would have had rather an opposite effect. The importance of consonance in securing greater audibility can, however, be traced in the practice of intoning as used in our large cathedrals.

The Bamboo Harmonicon, termed a *Marimba*, or *Balafo*, is furnished with a dried calabash or gourd beneath each resonating plate. A small hole is pierced into the cavity of the gourd and turned upwards towards the under surface of the plate. Around this hole is cemented a smaller gourd, with the two extremities removed, so as to form a cornet or receiver, evidently intended to direct a larger number of vibrations into the consonant cavity.

The determination and measurement of musical sound has, from the earliest times, been studied with success. Indeed, in the

monochord of Pythagoras we have an early machine which still remains of value. The "Pythagorean comma" is in frequent reference to this day, and his division of the string, followed by Euclid in the "Sectio Canonis," laid a foundation to the mathematical theory of music.

The Organ, whether in the hydraulic or pneumatic form, is the only other instrument involving scientific and mechanical construction which dates back to classical times. In the Hydraulic Organ, the principle of which is exhibited, fluid pressure was used to compress the air.

Whilst the monochord has, from the earliest times, illustrated the laws of strings, pipes have had no corresponding representative among scientific apparatus.

The organ itself, however, is essentially a great collection of apparatus whereby the tones of other instruments are imitated. We can easily recognise the characteristics of flute, trumpet, horn, voice, or string. Thus, while analysis of tone is modern, the artificial composition of tone has long been practised in organ pipes, and may still be advantageously studied in them; indeed, the mixture stops, known as "cornets" in old organs, were really an instinctive anticipation of Helmholtz's discoveries as to quality or timbre.

The materials of a pipe are either wood or metal, according to the form desired—wood being clearly suited for rectangular pipes, and metal for those of rounded or conical outlines; the material being selected more for the sake of solidity than for its influence upon tone.

Pipes fall into one of two great classes—flue and reed pipes—according to the mode in which the column of air is excited.

In flue-pipes the exciting cause is a sheet of wind passing over a mouth, exemplified in the case of a common whistle, which is, in fact, the representative of all flue-pipes.

Pipes, like whistles, form three groups, according as they are stopped at the end, half stopped, or entirely open. Each of

these groups has distinct characteristics. The stopped pipes have generally a soft and massive tone; the half stopped one, sweet and piercing; those entirely open, allowing a freer action of harmonics and setting more air in motion, give the more strident, although massive, effect peculiar to open diapasons.

These three groups are again subject to endless modifications of tone by the proportions of pipes; the diameter affecting those that are cylindrical, and the depth, from front to back, those that are rectangular. Moreover, the size of the sheet of wind at the mouth, the force of the blast, and its direction, can be made to evoke any peculiarity which the proportions of the pipe afford, and to give prominence to a certain set of harmonics, or to allow a relative succession of harmonics and fundamental, as in the case of the "Viol di gamba" pipe.

Reed-pipes, on the other hand, have their representative in the trumpet, where the vibration of the human lip, through which the wind passes into the tube, are the exciting cause. On examining a reed-pipe it will be seen how the "thrilling" lip is replaced by a metal tongue known as a "beating" reed.

Considering that any form of open or "shaded" tube can be applied to the reed in an organ, the great opportunity of varying tone, as compared with the trumpet, is evident, even if the reed were always the same; for, according to the proportions of the tube, and the gradual or rapid divergence of the cone, it is possible to give predominance either to the fundamental, or to a set of harmonics, or even to particular harmonics alone. But the reed can also be varied either as regards its pliancy, or its curve, or its freedom of motion.

In organs the reed employed is almost always a "beating reed," *i.e.*, the tongue cannot pass through the slit over which it is set, but strikes against it.

In free reeds the tongue can pass through without striking. Free reeds were introduced into Europe from China by Kratzenstein, and brought to perfection under Sir Charles Wheatstone.

They are used as the vibrators in harmoniums, and similar wind instruments. Their great recommendation is their cheapness and portability; since a note can be thus obtained without the conjunction of any sympathetic body or tube. They have, of course, the necessary defect of being unsympathetic and feeble in comparison with the organ. These defects are modified by the use of channels in harmoniums, by suction in the American organ, and by the use of shields and coverings for deadening and softening the sound.

Besides beating and free reeds, fresh combinations have recently been effected. The gradual development of a new condition of reed-power is illustrated by a collection of apparatus exhibited, tracing its history from the earliest Æolian types.

The simplest of these are found even among savages, who plant their spears in the ground and lie listening to the Æolian sounds.

A bow or a harp string was next found to have the same effect, and thus various forms of the Æolian harp are recorded in history.

Then came the more modern form claimed by Kircher, but more properly attributed to an Englishman named Pope. Then Schnell's anemochord, and other devices, the particulars of which are not recovered, making use of wind to set musical strings in vibration more or less sustained. Then we come to a peculiar arrangement of varnished ribbon or flat wire within a double organ-pipe, introduced by Professor Robison for evoking Æolian tones. Then a device for acting on one portion of the string only, as by Green and Wheatstone. The next change was in the adoption of a free reed tied by a silken thread to pianoforte wire, as in the instrument devised by Pope; then a reversion to the string alone, with one portion flattened and spread out to the whole force of the wind and preventing the lateral sway, as designed by Julyan; then the flattened portion replaced by a reed-tongue, with an attached wire in prolongation of length, as in Farmer's invention; then the reed-tongue separated from the prolonged string, and connected by a pin, as by Farmer and Hamil-

ton. Then come a series of experiments by Hamilton in conjunction with Hermann Smith, in which the reed tone is regarded apart from the string, and produced as an organ note, the string's functions analysed, and the string replaced by other bodies linked to the reed, and reacting upon it, and the mode of transmission to solid bodies investigated and illustrated. The discovery that reeds can obtain a sympathetic resonance from solid bodies leads to a new field of experiment. Reverting to experience, it is evident that besides the familiar instances of violin and organ-pipe, there exists in solid bodies the same power of strengthening and reacting upon a source of vibration.

We often hear organ-tones accidentally imitated in a large building. Thus the dragging of a bench across a marble floor will awake a grand violone sound; the shifting of a chair often gives rise to a clear trumpet tone; and sometimes the shivering of a great door as it slowly closes by its own weight rivals the note of the deepest pedal pipes. Such sounds cannot at once be discriminated from organ notes, but their want of continuity and of steady pitch robs them of all elements of grandeur, and reduces them to the level of noises.

In the large collection of apparatus contributed by Mr. Baillie Hamilton, we can estimate the chances of recovering to our use these sources of sound, necessarily ranking among their number the Æolian sounds, and sounds which have been often heard and enjoyed in nature, but which have not as yet been harmonised or controlled.

In the revival of mechanical methods, as applied to the determination of sound, which has taken place within the last century, an early instrument for computing vibrations continues to be of service, namely, Savart's toothed wheel; the teeth of which, rotating with a measurable velocity, are made to impinge on a resonant body, and the pitch of the note produced is compared with a standard.

But the tension and division of strings were also early utilised

in Longman and Broderip's Tuning Machine, which is exhibited, and which does not materially differ from the contrivances of Pythagoras.

Perronet Thompson followed the same system, in adjusting the so-called quarter-tones of his Enharmonic Organ. He used a monochord strung with steel wire, the adjustable weight rising regularly to 250 lbs.

Of late the Siren, in one or other of its forms, has been principally employed. A rotating disc, with oblique holes, is brought into close contact with a similar fixed disc, the obliquity of whose holes lies in the opposite direction; rotation is thus produced by the current of air, and a musical note by the alternate passage and obstruction of the stream; while a screw-counter registers the rapidity of rotation for a given pitch.

It is worthy of comment that the two mechanical principles thus laid down, have both been found ancillary to the measurement of the far more rapid vibrations of light; the toothed wheel in M. Fizeau's, and the siren in M. Foucault's experiments, recently repeated by M. Cornu with increased accuracy and elaboration.

Other modes of measurement are the Optical and the Graphical, severally connected with the apparatus of M. Lissajous, and the Vibration-Microscope of Helmholtz; with the curvetracers of Mr. Donkin and Mr. Tisley, and the Phonautograph. In the two former cases the figures obtained serve also to illustrate the phenomena of circular and elliptical polarization.

Lastly, the method of Beats and Interferences affords the best practical method of measurement for the purposes of tuning and comparison. These have of late been fully discussed in the great work of Helmholtz.

History and Ethnology.

It is of the highest moment here, as in other branches of science, to consider developments, now common and familiar, in the light of their history and distribution. It has been found practicable,

through the kind co-operation of Mr. W. Chappell, to present for exhibition a series of ancient Egyptian pipes, reproduced in *fac-simile* from those found in Egyptian tombs, preserved in the British Museum and Continental collections, with reeds complete, and to give a fair approximation to the scale on which they must have been played.

The applications of acoustical theory to music proper can only be very partially treated in a scientific exhibition. But the great discoveries of Helmholtz as to quality or timbre cannot be omitted. Apparatus for the illustration of the effect of "overtones" will be shown; as will be also several systems of true intonation as opposed to equal temperament. The chief defect of most of the former is the great complication of the key-boards. This is, however, ingeniously overcome in the Harmonium of Mr. Ellis, constructed according to the plan proposed in his paper on Duodenes, read before the Royal Society. In this instrument the usual twelve keys to the octave are retained, and the various notes are introduced by means of stops opening different combinations. Apparatus for illustrating the effect of heat and electricity on vibrating bodies is also exhibited.

The whole subject may be appropriately summed up in the following propositions:—

1. The respective influence of scientific apparatus on the art of music, and *vice versâ.*

At the very outset we meet with the monochord of Pythagoras, a machine which at once yielded immense practical results to music. We then enter into a long period during which instrumental appliances grew, but without design, and without theory. The discoveries of new or improved instruments were purely technical, often fortuitous; although every new member added was a piece of mechanism open to scientific analysis.

During the last century a return has been made to apparatus essentially scientific, for the explanation of what had been musically invented, and soon after we find,

2. The reciprocal influence of instruments on apparatus—no better instance of which can be found than the discovery of Tartini's "Terzo Suono," or third sound; originally taught by the great violinist to his pupils as a means of accurate tuning, but involving a new and important acoustical principle.

3. In many cases instruments of music actually stand in the place of apparatus. Strictly considered, a musical note is of itself a mathematical fact; quite independent of its power of exciting emotion and pleasure by its artistic production. On the other hand, tuning and intonation, originally left entirely to the accurate and cultivated ear of a skilled performer, have become a branch of science, with definite laws and practical rules; insomuch that the instinctive departures from a fixed tuning, which the older violinists made by a kind of instinct, are now explained, and even the disposition of various instruments with differing qualities in an orchestra is shown to be correct, or the contrary, according as the harmonics of each peculiar tone are consonant or dissonant.

LIGHT.

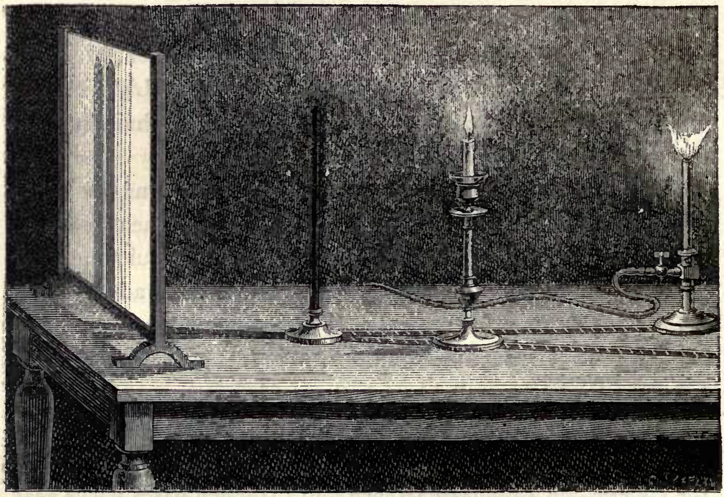
I.—Optical Instruments.

The instruments used in this branch of science may conveniently be grouped under the following heads, viz., Production, Measurement of Intensity and Velocity, Action of Matter on Light, Action of Light on Light, Action of Light on Matter, Technical Applications of Optical Principles.

The most obvious source of light is the sun; and for many experiments ordinary daylight is sufficient; but when great intensity is required direct solar beams reflected by suitable appliances in the direction required are used. One great advantage of light from this source is, that the rays are approximately parallel; while with light derived from other sources it is generally necessary to render the rays parallel by a system of lenses.

The instruments in general use for the production of light are the lime-light and the electric-light. The lime-light is produced by the combustion of mixed oxygen and hydrogen gases which play upon a cylinder or cake of lime. Common coal gas is sometimes substituted for hydrogen, but in that case the consumption of oxygen is greater. The gases are sometimes contained in bags placed under pressure, but it is now usual to compress them in bottles of wrought iron. The jets used with hydrogen and with coal gas are slightly different. Zirconia cylinders have been suggested instead of lime; when these are thoroughly calcined they answer well, but they have never become the subject of general manufacture.

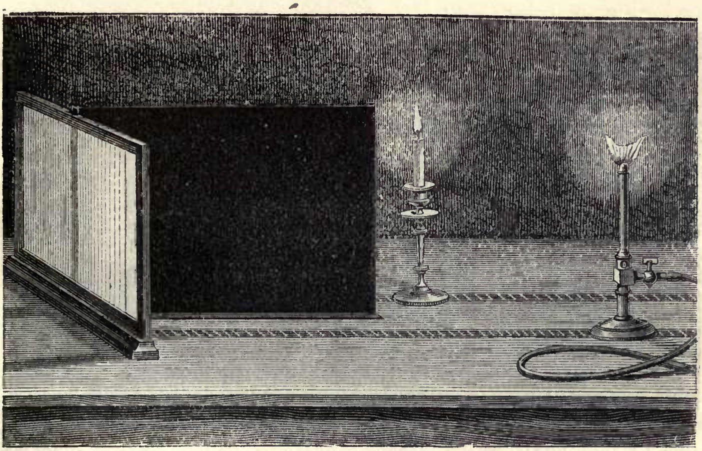
The electric-light is far more intense, and it more nearly approaches to a point of light, as distinguished from an illuminating surface, than the lime-light; it requires, however, a more elaborate lamp, and more skilful attention while in action. The light is produced by the incandescence of carbon due to an intense electric current. For this purpose 40 or 50 Grove's or Bunsen's cells are generally employed. Various forms of lamp have been constructed, and there still remains more to be done in this direction. The two most generally in use are, first, Serrin's,



which is better adapted to purposes of general illumination than to optical experiments, it is largely so used in France; and, secondly, Foucault's Regulator as constructed by Duboscq. For the battery various dynamo-electric machines have been substituted, such as Clarke's, Holms's, Wilde's, and latterly Gramme's, which last, although the most effective, is yet in an early stage of development.

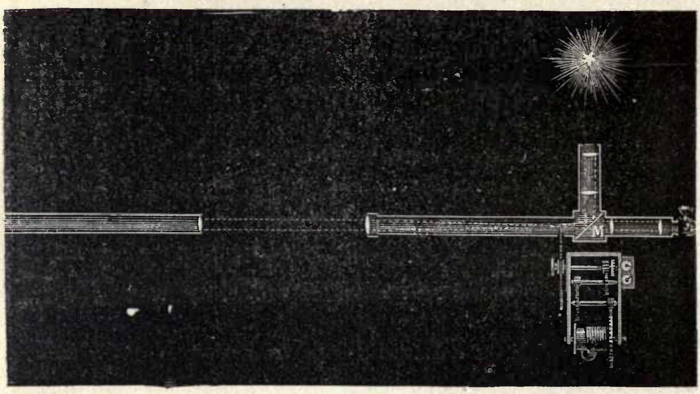
Other machines for the production of electric currents will be mentioned under electricity.

For measuring the intensity of light various photometers have been invented, such as that of Rumford, in which the illuminations of two shadows of the same object produced by two sources of light are compared; that of Bunsen, in which the light transmitted through stearined paper is compared with that from another source reflected from unoiled paper. In Bouguer's photometer comparison is made of the brightness of two portions of a surface, separately illuminated by light from two sources; one of the sources is then removed further off or nearer until the illumination is equal. Ritchie's photometer is based on the



same principle, and somewhat simpler. To these others might be added, but the majority are modifications of the above. Wheatstone suggested a form depending upon the relative colours of polarised light; but as the eye is more sensitive to differences of intensity than to those of tint the principle does not seem promising. Recent investigations on the action of light upon the electric conductivity of selenium, seem to show that this action may conversely be used for photometry. Lastly, Mr. Crookes has proposed to use his radiometer, mentioned below, for the same purpose.

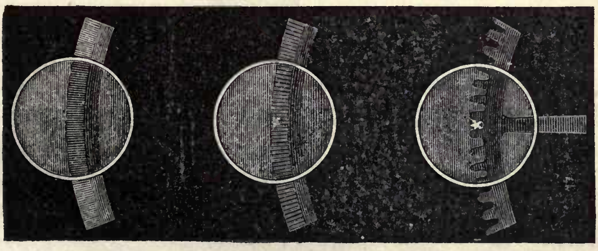
The velocity of light is not only a very interesting subject in itself, as one of the great physical units to be determined, but is also of the highest importance in connection with astronomy. Various methods have been devised for determining it. Omitting, as apart from the present subject, indirect means, mention must be made of the method of the revolving mirror, as used by Foucault, and that of the toothed wheel adopted by Fizeau. In the former case, a beam of light reflected from a revolving mirror is again reflected normally by a fixed concave mirror. During the time occupied by the passage of light from the first to the second



mirror and back, the revolving mirror has undergone a slight angular motion, which produces a small deflection of the beam. From this deflection the velocity of light may be computed. In the second method, a beam of light passes between the teeth of a revolving toothed wheel, and it is then reflected back along the same line from a mirror some miles distant. In general during the revolution the observer will see the light so reflected as a luminous point; but at certain rates which form an arithmetical series the light will be extinguished by an intervening tooth. With a triple rate it will be again seen, and so on. From observations on the rates for which the light ceases to be visible the

velocity of light may be calculated. These experiments have been recently repeated, on a very large scale, by M. Cornu, at the Observatory in Paris.

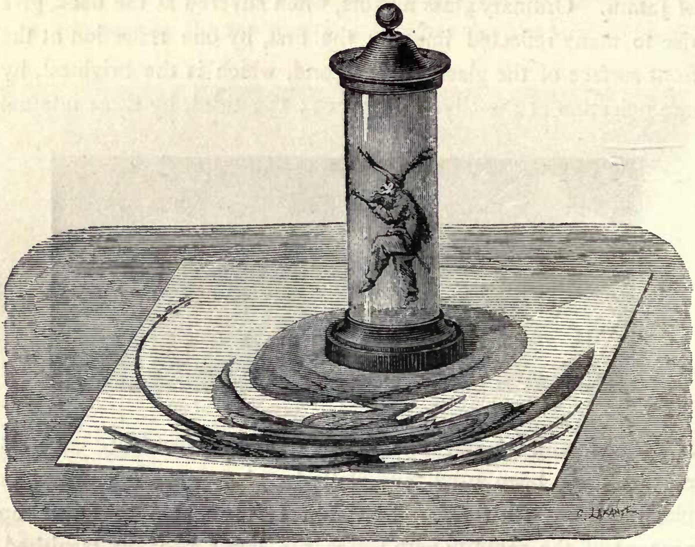
For the verification of the general laws of reflection instruments have been devised in which, the incident ray being fixed, the reflecting surface is capable of being turned through any required angle, and in which the corresponding angle of the reflected ray is registered on a divided circle. Such, for instance, is the apparatus of Jamin. Ordinary glass mirrors, when silvered at the back, give rise to many reflected images; the first, by one reflection at the front surface of the glass; the second, which is the brightest, by one reflection at the silvered surface; the third, by three internal



reflections, and so on. To avoid this inconvenience metallic mirrors have been used, and, latterly, glass mirrors silvered or platinised on the front. Platinum is preferable to silver on account of the rapidity with which the latter becomes tarnished. But, owing to the great heat to which the glass must be subjected, it is found very difficult to preserve the reflecting surface from distortion. It is much to be regretted that, apparently owing to these difficulties, the manufacture has been discontinued, both in this country and in France.

Convex spherical mirrors are used only for demonstrating optical laws, and for decorative purposes. It has been suggested that they still have another scientific signification, viz., that the images produced may be regarded as diagrams appertaining to a non-

Euclidean space, in which form and magnitude do not remain the same when a figure is moved from one part of space to another, but are themselves functions of the position. Cylindrical and conical mirrors have been used for showing the effect, known as the anamorphosis, whereby drawings suitably distorted are restored to their proper proportions. Conical mirrors, or reflecting cones, which must be of glass, serve also for producing radial polarisation. Parabolic, and other curved mirrors, are used in light-



houses for illumination, and in reflecting telescopes. The rays from a luminous point, placed in the focus, are reflected by a parabolic mirror in a parallel beam of light; and conversely parallel rays, as those from the sun, are collected by parabolic reflectors at the focus.

The amount of light reflected from the surfaces of various media, and at various angles, has been the subject of much careful experiment. When the light is polarised the question becomes a very profound one.

In connection with the subject of reflection mention should be made of instruments designed to send a beam of solar light in one definite direction at all hours of the day, by means of clock-work. Among these the best known are Foucault's and Silbermann's Heliostats. A somewhat simpler and less expensive instrument has been devised by Professor Stoney. But the most perfect of all is that known as the Siderostat, described under the head of Astronomy.

It would perhaps be going too far into detail to enter upon the subject of quadrants, sextants, reflecting circles, &c., used for the astronomical and geographical determination of latitudes, and for surveying.

Refraction, or the bending which a ray of light undergoes in passing from one medium to another, varies, as is well known, with the media used in the experiment, with the angle of incidence, and also with the colour of the light. Instruments on the same principle as those used for reflection are employed for determining refraction. The quantity which is the subject of measurement, is the ratio of the sines of the angles of inclination of the incident and refracted rays respectively, to the normal of the bounding surface of the two media at the point of incidence; or it is, what is the same thing, the ratio of the velocities of light in the two media. The principal instrument in aid of this question, as well as many of those which follow, is the prism, whereby the rays composing white light are variously refracted or dispersed. This can be used for the question of refraction if we employ monochromatic light such as that produced by sodium or by spirits of wine and salt. Or more generally, it can be so used if we employ as a source of light a spark producing a bright line spectrum, and take account of one bright line only at a time. Or again, it can be so used, if we employ solar light and register the results obtained in respect of only one dark line at a time.

If the substance be solid and transparent, it can be cut into a

prism of the required angle. If it be liquid, a hollow prism of glass or of quartz, filled with the liquid, is used. Care must be taken that the plates forming the sides of such prisms have truly parallel sides, or faces. In all these experiments for the determination of refractive indices the rays should pass through the prism with minimum deviation; viz., the incident and emergent rays should make equal angles with the surfaces.

Since the two faces of the prism are of necessity inclined to one another, it follows that every ray in its passage must undergo a deviation or turning from its original course; and it is sometimes desirable to bring back the ray to its original direction, or, technically speaking, to correct the deviation. This is effected by placing beyond the first a second prism, in a reverse position, of a substance having greater deviating and less dispersive power than the first. By putting together a train of such prisms alternately, direct-vision prisms have been constructed; these disperse the light, but for one particular ray, usually one belonging to the yellow part of the spectrum, do not cause it to deviate. This can, of course, be effected accurately only for rays having a particular refrangibility, that is to say, of a particular period of vibration. The same principle, carried still further, is employed in forming compound achromatic prisms and lenses, the object of which is to correct the colours otherwise produced by the dispersion due to a single lens; or, more strctly speaking, to contrive a common focal length for all colours.

Light when of one colour, or monochromatic, consists of rays of one period of vibration, and consequently of one refrangibility only. The spectrum of such light would consist of a single bright line only. A particular beam of light may be due to waves of various but definite periods; in that case the spectrum will show lines corresponding to those lengths only; it will be what is called a bright line spectrum. Such are the spectra of the metals when vaporised and rendered incandescent by an electric current. Such are the spectra of gases as a general rule. But this subject, if pursued

further, would lead us beyond our present limits into the region of solar physics.

In the case of common light colour is due to absorption; that is, to the extinction of one or more of the components of white light, and to the transmission or reflexion, as the case may be, of the remainder. The lost rays are transformed mainly into heat. This process is selective, and the selection may extend to any number of the components; so that the spectra of such colours will show dark bands in the places of the colours absorbed. The bands always retain their position whenever the same substance is used; hence they may be used for detecting the presence of colouring substances in solution.

A very important instance of absorption is that exhibited by metallic vapours. Vapours of metals at a lower temperature absorb exactly those rays which they emit at a higher. This is the great principle first distinctly enunciated by Kirchhoff, and made by him the foundation of modern solar physics. The vapours of metals in a state of incandescence on the surface of the sun float upwards, and thus form a stratum of cooler vapours which exert selective absorption upon the light before it reaches us. The celebrated dark lines of Fraunhofer in the solar spectrum are due to this selective absorption. Much time and pains have been expended upon the construction of accurate maps of these lines by Ångstrom, Thalen, Kirchhoff, and others. More recently, Lockyer has applied photography to laying down these lines; the map of the solar spectrum upon which he is now engaged will probably not only exceed all predecessors in accuracy, but will add to an enormous extent to the number of the ascertained lines in the spectrum.

A variety of spectroscopes or arrangements of prisms with suitable telescopes or lenses for observation will be found in the Collection. Some of them have few, or even only one prism, and are intended for feeble light; others have many prisms. In some the light will be reflected back, and sent twice, or even three

times, through the same train of prisms. In some the greatest effects are sought in wide dispersion; in others they depend upon high magnifying power; but the value of each of these varieties will depend upon the purpose to which the instrument is to be devoted.

It is perhaps hardly necessary to mention here that the spectroscope has been the instrument with which the great discoveries in chemistry and solar physics have been made within our own time. Among the first investigators in the study of metals by spectrum analysis was the late Sir. C. Wheatstone. The discovery of new metals by the same process has been largely due to Professors Kirchhoff and Bunsen, in Germany; and Roscoe and Crookes in our own country have added much to our knowledge by the use of the same instrument. While the application of the same method to the great questions of solar and celestial physics has been the subject of the labours of Frankland, Lockyer, and others, in this country; of Jansen in France; and of Respighi, Secchi, and others in Italy; it would be impossible within the present limits to do justice to all the claims of workers in spectroscopy; but the labours of Rutherford and Draper, in America; of Jamin and others in France, as well as those of our own countrymen, deserve an honourable mention in connection with the application of photography to the study of the more refrangible part of the solar spectrum.

The applications of this branch of optics to practical purposes are as yet doubtless in their infancy, but the spectroscope has been applied, not merely to the detection of metals by their bright lines, and of other substances by their absorption bands, but Mr. Lockyer has suggested a process for quantitative analysis by means of measurements of the lengths of the bright lines developed in the spectra of the incandescent vapours of metals under combustion.

Light is said to be polarised when it presents certain peculiarities which it is not generally found to possess. These peculiarities, although very varied in their manifestations, have this feature

in common, that they cannot generally be detected by the unassisted eye; and, consequently, special instrumental means are required for their investigation. The phenomena which are among the most splendid in the entire range of optics must be witnessed to be appreciated or understood; and the instruments described below constitute the means for rendering them visible. The explanation of the facts is to be sought in the wave theory of light, by means of which not only have many very diversified phenomena been connected together, but in some cases results have been actually predicted. According to this theory light is due to the vibrations of an elastic medium called ether, which is supposed to pervade all space. The vibrations take place in planes perpendicular to the direction of the ray; and the paths or orbits are straight lines, or circles or ellipses. In a ray of common light the orbits of an ether particle are subject to incessant and irregular changes in form and position, but in a polarised ray all the orbits are similar and similarly situated: and the process of polarisation is understood to consist in bringing all the orbits into similar positions.

For the exemplification of this theoretical side of the subject various forms of instruments have been devised, the most comprehensive of which is known as the wave machine of Wheatstone. The object of this instrument is to exhibit the results of the combination of various kinds of vibrations meeting at various phases of their motion. Another form of apparatus for illustrating wave motion is exhibited by Mr. Woodward, of Birmingham.

For plane polarisation of light three methods are in general use —reflexion from glass or other non-metallic substance, refraction through a plate, or, better still, through a bundle of glass plates, and double refraction by crystalline media. The same methods serve for analysing light so polarised. Instruments have been devised upon the bases of all these methods. In the polariscope of Nörrenberg provision is made for the application of the first two methods; in others the third method is used. The crystals generally employed are tourmalines and Iceland spar. Tourma-

line has not only the property in common with other doubly refracting crystals, of polarising every ray which it transmits, but also it absorbs the ordinary rays, and thus produces what is generally required, a single beam of polarised light. Iceland spar, on the other hand, generally produces two beams; and various expedients are adopted for getting rid of one of them: sometimes one of the beams is shut off by a screen, but more often the ordinary beam is thrown out of the field by means of the well-known instrument called the Nicol's prism. In Nörrenberg's instrument, as constructed by Hofmann, in Paris, as well as in another by Soleil, a tourmaline is used as polariser, and a Nicol's prism as analyser.

Duboscq has for many years past constructed a polariscope for projection, by means of which every ordinary experiment in polarisation may be thrown on the screen. The construction and use of this instrument are alike rather difficult, owing to the small size of the Nicols and double-image prisms employed; but these difficulties have been obviated by the construction of Nicol's prisms of a larger size, viz. giving a clear field of 2 inches to $3\frac{1}{2}$ inches in diameter. A pair of such Nicols $2\frac{1}{4}$ to $2\frac{1}{2}$ inch field, with suitable lenses and other appliances, is exhibited; these were, in fact, the first of this size, and their construction, under Mr. Ladd, forms an epoch in the annals of polarisation. Another, constructed by Ahrens, is exhibited; this, which has a field of upwards of $3\frac{1}{2}$ inches, is the largest and purest yet constructed.

Besides the Nicol's prism there is also another by Foucault, in which the second ray is similarly thrown out of the field. This is much shorter than the Nicol's prism, requires less spar, and is more convenient for experiments on heat; but in order to use advantageously the entire field, the rays passing through it should be strictly parallel.

To Professor Jellet is due the invention of a new analysing prism, by means of which the plane of polarisation may be determined with great precision. It consists of a long prism of Iceland spar, which is reduced to the form of a right prism by

grinding off its ends, and sliced lengthwise by a plane nearly, but not quite, perpendicular to the principal plane. The parts into which the prism is thus divided are joined in reverse positions, and a diaphragm with a circular opening is placed at each end. The light which passes through both diaphragms produces a circular field divided by a diametral slit into two parts, in which the planes of polarisation are slightly inclined to one another. If the light which has been previously plane polarised be transmitted it will be extinguished in the two parts of the field which lie close together, and the light will become uniform in a position midway between these. This position determines the position of the original plane of polarisation with great precision.

The light from certain parts of the sky is, as is well known, polarised; and the plane of polarisation depends upon the position of the sun. Based upon this fact the late Sir Charles Wheatstone constructed a polar clock, in which the hour angle of the sun, and consequently the local time, is approximately determined by observing the position of this plane of polarisation.

The interference of rays of polarised light for all differences of path was first made the subject of direct experiment by MM. Foucault and Fizeau, who showed the bands occurring in the spectrum of such light after its passage through plates of crystal. The same method may be employed for explaining the phenomena of colour when the plates are thin; and remarkable forms of interference curves are produced in the spectra when crystal plates of varying thickness are introduced. Apparatus combining the spectroscope and polariscope for these experiments will be exhibited. A polariscope, with a rapidly revolving double image prism as analyser, was invented, independently and almost at the same time, by Professor Mach in Vienna, and Mr. Spottiswoode in London, for showing simultaneously, instead of successively, all the phases of rotatory and other polarisation. The principle can be applied to eye observations and to projection.

A compound analyser is also exhibited. This consists of two or

more double image prisms, with quartz plates intervening, and has been used for studying the combination of colours, as well as for the effects of *couleurs degradées*, first discussed experimentally, although by another method, by Helmholtz. Another application of rotatory polarisation consists in determining the amount of rotation of the plane of polarisation due to a column of given length of saccharine and other solutions. The instrument whereby this, and consequently the strength of the solution, is determined, is known as the saccharimeter.

One of the most remarkable phenomena connected with double refraction is that known as conical refraction. This phenomenon, which was predicted by the late Sir W. Hamilton as a consequence of the wave theory, was first actually observed by Lloyd. It depends upon the fact that the wave surface, or locus of plane waves diverging from a point within a crystal, presents certain singular dimple-like points; at the bottom of the hollow the tangents arrange themselves in a cone instead of a plane; while on the elevated parts in the neighbourhood of these points the tangent plane meets the surface in a ring. Rays which have traversed the crystal in the direction of one of these points emerge in a cone; while those which have traversed it in a cone, so as to meet one of the rings, emerge in a cylinder of parallel rays. The first of these cases is called external, the second internal conical refraction. For a long time arragonite was the only crystal used for the study of conical refraction; but recently M. Nodot has shown that crystals of sugar, bichromate of potash, and tartaric acid will serve equally well for the purpose.

Some substances possess the property, first investigated by Professor G. G. Stokes, of apparently changing the colour of light, or, more strictly speaking, of giving out radiations of a different period of vibration from those which they received. The change is usually from a colour of a higher to a colour of a lower degree of refrangibility. Uranium, often used as an ingredient in the manufacture of glass, gives out a canary colour; sulphate of quinine a blue

colour; decoction of esculine a brown, &c. These were among the substances first studied, but many others are now known to possess the property. Fluorescence has been employed for studying the invisible part of the spectrum beyond the violet.

The remarkable experiments of Mr. Crookes on the repulsion, connected with radiation, of light bodies suspended in a highly-exhausted chamber have suggested a new method of measuring radiation, or radiometry, as it is now generally termed. The main facts of the experiments are as follows: If a beam of light falls upon a light body suspended in a chamber which has undergone only moderate exhaustion, the body is attracted. This fact was previously known, and it is attributed to convection currents. If the exhaustion be carried still further, the attraction diminishes and finally ceases. If the exhaustion be carried still further repulsion ensues. To effect this degree of exhaustion Mr. Crookes found it necessary to improve upon Sprengel's pump. The amount of repulsion depends upon the colour, the substance, &c., of the body suspended, and also upon the wave length of the rays of light falling upon it. Various forms of these radiometers will probably be exhibited.

Next to polarisation, the most important branch of optics for the study of the nature and properties of light is that of interference and diffraction. This leads directly to the measurement of the lengths of the waves of light. In what sense the term waves is ultimately to be understood is a question which must some day be answered by molecular physics; but whatever be that answer, it is at all events certain that the phenomena of light are periodic both as regards time and space, and the wave theory of light is undoubtedly the only theory which has as yet stood the test of experiment. The fundamental experiment of producing interference by throwing together two rays of light by means of two mirrors slightly inclined to one another forms a starting point in this part of optics. As a complement to this we have the corresponding experiment with the biprism. This is an instrument

consisting of a plate of glass, one side of which is plane and the other is bounded by two planes, forming a very flat penthouse or roof. In both these experiments the light, which really emanates from one source, appears as if it emanated from two points very near to one another. We thus have the confluence of two sets of rays in the same phase of wave motion, which is an essential condition in order that interference may take place. The biprism is more convenient for use than the mirrors, but the calculation of wave lengths is rather longer.

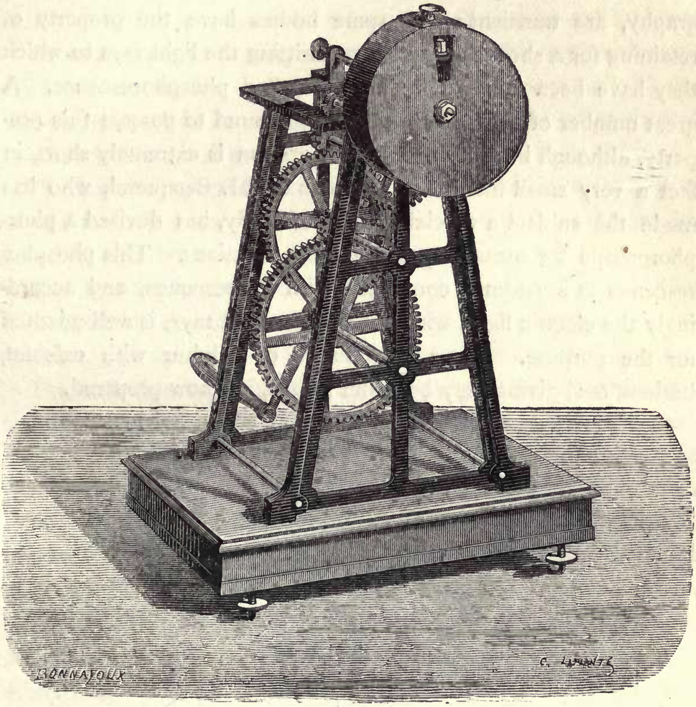
Intimately connected with the foregoing is the subject of the colours of thin plates, noticed first by Boyle, then by Hooke, and afterwards in a much more complete manner by Newton. The apparatus for these experiments, consisting of two glass plates compressible by screws, is to be found in every laboratory.

Interference of rays emanating from the same source is also effected by diffraction, or the bending of luminous rays in their passage near the edges of sharply defined objects. The phenomena so produced are minute in dimensions, and are therefore not generally adapted for projection. They are, however, extremely beautiful when observed by the eye in a well-adjusted apparatus. This consists mainly of screens, with openings of various forms and sizes, supported on suitable stands with screws and other appliances for position. These are usually fixed in grooves on a strong iron frame called an optical bench.

The diffraction figures, which are of course altogether different in form from those of the apertures to which they are due, have been the subject of much mathematical discussion. Bridge, to whom some very general theorems are due, devised a very convenient form of apparatus, with apertures photographed on a glass plate, by means of which a great number of beautiful figures may be readily produced.

There is a peculiar class of diffraction plates called gratings or *réseaux*, which is of great importance. These consist of plates of glass having a large number of very fine lines ruled upon them.

The lines are sometimes formed by cutting through a film of silver deposited on the glass. Lord Rayleigh has succeeded in photographing these lines, and thus obtaining comparatively inexpensive gratings. The number of these lines varies from two to six thousand or even more in the inch. When light, admitted through a



Becquerel's Phosphoroscope.

narrow slit, is allowed to fall upon one of these a spectrum is formed, or rather a series of spectra, of increasing width on either side from the centre outwards. Of these the first two or three are tolerably distinct, but beyond this they overlap so much that they can only be disentangled by means of Fraunhofer's lines, or by some other fixed lines or bands in the spectrum. The spectra

formed by gratings are called normal spectra on account of the absence of the unequal dispersion due to prisms in which only one ray can pass at the angle of minimum dispersion. They have been much used in determining wave lengths, as by Angström, Thalen, and others.

The effects of light so far noticed, with the exception of photography, are transient; but some bodies have the property of retaining for a short time and of re-emitting the light rays to which they have been subjected. This is called phosphorescence. A great number of substances have been found to possess this property, although in many cases the duration is extremely short, in fact a very small fraction of a second. M. Becquerel, who has made the subject a special subject of study, has devised a phosphoroscope for measuring these short durations. This phosphorescence is apparently connected with fluorescence, and accordingly the electric light, which is rich in violet rays, is well adapted for the purpose. Some compounds of sulphur with calcium, barium, &c., giving very beautiful results, are now prepared.

WM. SPOTTISWOODE.

II.—Photographic Printing Processes.

White light, and certain of its coloured components, have the power of splitting up into simpler forms the molecules of certain kinds of matter, in a manner analogous to that possessed by heat.

In some cases the change is only effected after very prolonged exposure, as in the case of certain kinds of glass and of the aniline dyes, whilst in others it is very rapid. The latter class of bodies are impressed into the service of photography.

The bodies most generally known to be sensitive to the action of the luminous rays are compounds of silver, such as the iodide, chloride, and its more complex organic salts.

The light separates these into more elementary forms, and when it is controlled by a lens, or by being passed through a photographic negative, a picture can be obtained formed entirely of metallic silver.

The earliest known photographs (by Wedgewood) were produced on silver chloride. Sir John Herschell, amongst others, experimented with silver chloride, allowing, in some instances, a fine precipitate of this salt to be deposited by subsidence on glass. When washed with a dilute solution of silver nitrate, and dried, he exposed the sensitive layer in the camera. The picture of the 40-foot telescope that is exhibited, is the earliest known photograph on glass, having been obtained in 1839. At a later date, Nièçphore de Nièpce discovered that the bitumen of Judæa, or asphaltum, when exposed to light, became insoluble in the usual menstrua employed for dissolving it. An early picture, produced in the camera, of Kew Church, of the date of 1824, is still preserved in the British Museum. This discovery of Nièpce's is still utilised in certain photo-engraving processes, and although the method is slow, the resulting images have certain qualities of the highest importance. Of late years what is erroneously termed carbon printing has been much adopted by photographers. If a solution of a dichromate of an alkali be mixed with certain organic

compounds, such as gelatine or gum, dried, and be then exposed to light, a singular change takes place; the chromic salt gives up a certain proportion of its oxygen to the organic bodies, and the new compound thus formed becomes insoluble in water. If paper be coated with a mixture of gelatine, pigment of any kind, and potassium dichromate, and be exposed under an ordinary photographic negative, the gelatine will become insoluble to a depth dependent on the intensity of the light passing through the various portions of the negative, nearly all the surface of the gelatine next the glass becoming insoluble. If the paper thus prepared and exposed were placed in hot water the soluble gelatine imprisoned between the paper and the exterior insoluble surface of the film could not be washed away, an artifice is therefore necessary to enable the picture to be developed. This consists in causing the film to adhere to a temporary support, placing it in warm water, and then peeling away the paper. All the gelatine not insoluble can now be washed away, and the picture is fully developed. When thus finished it can again be transferred to paper, or can be left on the support; in the latter case, in order to get a picture in proper position, the negative must be what is called "reversed." In this class of printing the image is formed of gelatine, and the intensity is mostly dependent on the character of the pigment it contains. The autotype process is an example of this kind of photographic printing. If an image formed of gelatine be supported on a thin homogeneous film, an impression of it can be taken on a soft metal plate, as in "nature printing." When coloured liquid gelatine is run into the mould thus formed, and paper backed by a perfectly flat hard plate is brought down on its surface, the excess of coloured material is squeezed out. The paper can be removed, bearing the "set" gelatine image with it. Such is a bare outline of the Woodbury Process, specimens of which, with a gelatine film and mould, are shown.

There has been a further extension of this action of the dichromates of the alkalies on gelatine, during the last few years. Not only does the gelatine become insoluble when acted upon by

light, but it refuses to absorb water. Advantage is taken of this fact to prepare surfaces from which pictures can be printed in printers' inks in an ordinary type or lithographic press. If a glass plate be coated with a mixture of gelatine and potassium dichromate (with an addition of either gum resin or chrome alum to give the film hardness), and be then exposed to the action of light that passes through a negative, the different portions of the film of gelatine will have become absorbent of water in the exact proportion to the intensity of the light acting through the negative. If the plate be plunged into cold water for a time, and after the excess of water has been sponged off, a soft roller, coated with greasy ink, be passed over the gelatine, the full depth of ink will adhere to those portions of the image which have been strongly acted upon by light, and the different shades of the picture will be formed by the varying proportions of greasy ink that the film of gelatine is capable of holding, a power that is altogether dependent on the intensity of the light that has acted on it, and the consequent varying absorption of water. When a picture is thus formed in greasy ink, the gelatine film (which may be supported on the original glass plate or on a metal plate) may be placed in the printing-press, paper laid on it, and an impression taken. The surface may then be damped and rolled up again, and more impressions pulled. The Albertype, Heliotype, Pantotype, and the Autotype mechanical processes are all of them modifications of the above.

Photo-lithography is equally dependent on the reducing action of light on dichromated gelatine. In some processes the gelatine with which paper is coated, and which has not been acted upon by light, is washed away; the whole surface of the film having been coated with a layer of greasy ink subsequent to its exposure beneath a negative picture of a plan or map. In such examples the lines are formed of altered gelatine holding on its surface a layer of fine ink. The transfer, as this finished print is termed, is placed on a lithographic stone, pulled through the lithographic press, and impressions taken in the usual way.

When paper is washed over with the dichromate of an alkali, dried and submitted to the vapour of aniline, a blackening will be apparent. When light, however, has reduced the chromic salt, the surface will remain unchanged. In Willis's aniline process advantage is taken of this reaction. A map or plan is placed over the sensitized paper, and after exposure to light, it is submitted to the vapour of aniline. A print is thus obtained at one operation without the aid of a negative picture.

The methods of producing relief blocks for setting up type by means of photography are various. One of the most successful is by exposing a zinc plate coated with asphaltum beneath a negative, and then dissolving away those portions unchanged by light. The zinc, which is uncovered, is acted upon by acid, and after certain precautions are taken, a depth is obtained sufficient to allow an impression to be taken in the printing press as if it were a wood-cut. Gillot's is a good example of a photo-relief process.

There are other metallic and organic compounds which are acted upon by light. The ferric and uranic salts are all more or less reduced to the ferrous and uranous state when in the presence of organic matter, such as paper, gelatine, &c. Some examples of early prints produced by their aid will be found in the exhibition.

Vidal's polychromatic process is a carbon process: a negative of the subject is first obtained, and others are reproduced from it, the number depending on the number of colours to be printed. When it is desired that any portion of a print should have some particular tint, one of the negatives is utilised, and all but the required portions of it painted out with any opaque paint. A gelatine picture of the necessary tint is printed, and by means of a system of registration is placed accurately over a print of the whole subject, which has been previously made in neutral or other suitable colour as a ground. Thus, one after another, the films of various transparent colours are super-imposed till the polychromatic picture is built up. The process is analogous to chromo-lithography.

W. DE W. ABNEY.

INSTRUMENTS EMPLOYED IN HEAT INVESTIGATIONS.

THE various branches of Physics are so closely allied, and each requires for its proper investigation so much assistance from the others, that classification without much repetition is barely possible. But the difficulty is immensely greater when we endeavour to separate from one another the various subdivisions of one particular branch. We will, therefore, not try to draw any hard and fast lines; preferring a moderate, and probably useful, amount of repetition to the hopeless attempt to obtain a classification in which each head shall be entirely independent of the others. This being clearly understood, we may usefully divide our subject as follows:—

1. Nature of Heat.
2. Effects of Heat.
3. Measurement of Heat and Temperature.
4. Sources of Heat.
5. Transference of Heat.
6. Transformations of Heat.

Of these we may remark, generally, that there is a very close connection between the groups (1), (4), and (6), whose subjects are, in the main, recent additions to our knowledge; and that (3) depends, at least in all its ordinary practical forms, on some

application or other of one of the group (2). Let us take these up in order.

I.—Nature of Heat.

What we now know to be the transformation of mechanical energy into heat by friction has been habitually effected by savage man from time immemorial. The converse transformation, that of heat into work, dates back to the time of Hero at least. But the knowledge that a certain physical process will produce a certain result does not necessarily imply even a notion of the "Why;" and Hero as little imagined that in his Œolipile heat was *converted into* work, as do savages that work can be *converted into* heat.

That heat is one of the many forms of what we now call Energy, was all but established by Rumford and Davy at the very end of last century. It was first, however, clearly stated by Davy in 1812. Rumford's observations on the heat generated in the boring of cannon lead to an estimate of the mechanical value of heat, which is only about 20 per cent. too great.

The extensive, and exceedingly accurate, experiments of Joule led, in 1843 and subsequent years, by processes depending directly on friction, to numbers varying from 770 to 774 foot-pounds of energy as the equivalent of one unit of heat on the Fahrenheit scale. The number finally assigned by Joule (for the latitude of Manchester) is 772, and it is almost certainly not in error by anything approaching to 1 per cent.

In 1853 Joule verified this result by means of a very accurate determination of the specific heats of air, and a direct experimental proof (given in 1845) that the heat developed by the sudden compression of air is very nearly the equivalent of the work expended.

Direct measurements of the heat produced by the expenditure of mechanical energy were made in various ways by Colding, in 1843; and have been repeated in many forms by Hirn, Regnault, &c., since the publication (in 1849) of Joule's final result.

The direct verification of the fact that heat disappears when work is done by a heat-engine, unsuccessfully attempted by Séguin in 1839, was first effected by Hirn in 1857.

A great variety of indirect methods of approximating to the mechanical equivalent of heat have been successfully applied within the last thirty years by different experimenters. The earliest are, of course, those of Joule effected in 1843, and subsequent years by means of magneto-electricity.

The results of all such experiments are briefly summed up in the statement known as the

First Law of Thermodynamics.

When equal quantities of mechanical effect are produced by any means from purely thermal sources, or lost in purely thermal effects, equal quantities of heat are put out of existence or are generated. And, in the latitude of Manchester, 772 foot-pounds of work are capable of raising the temperature of 1lb. of water from 50° F. to 51° F.

Perhaps no purely physical idea has done so much to simplify science, or led to so many singular and novel predictions (subsequently verified by experiment) as has Carnot's idea of a *Cycle*, or his farther idea of a *Reversible Cycle* of operations.

It has given us not only the legitimate mode of finding the relation between heat and work in an engine, but also the test of perfection for a heat-engine, an absolute definition of temperature, the effect of pressure on the melting points of solids, and innumerable important groups of associated properties of matter and energy under various conditions. To a great extent these are included in the statement of the

Second Law of Thermodynamics.

If an engine be such that, when it is worked backwards, the physical and mechanical agencies in every part of its motions are all reversed, it produces as much mechanical effect as can be produced by

any thermodynamic engine, with the same temperatures of source and refrigerator, from a given quantity of heat.

It is to be particularly observed here that *Reversibility* is the sole test of perfection of an engine. Also in the working of a reversible heat-engine nothing is said about the nature of the working substance; the temperatures of source and refrigerator, and the quantity of heat supplied, are the sole determining factors of the work which can be done. The importance of this proposition, as regards actual and proposed engines, cannot be overestimated.

II.—Effects of Heat.

These are so numerous that we can attempt to classify only a few of the more important. For, in fact, far the greater part of the energy which is at our disposal is due to the past or present radiation from the Sun. Even Light is merely a high form of radiant heat, but, except in so far as it is a form of energy it does not come in for consideration in the present branch of our subject. Without the radiant energy which the sun now supplies us, or has supplied us in bygone times, our whole stock would consist only in Tidal Energy, the Earth's internal Heat, and Primæval Potential Energy of uncombined chemicals such as native iron, native sulphur, &c. The first of these is the only one which promises to be of much use, but it has not to our knowledge been utilised, at least to any great extent.

We may classify the Effects of Heat as follows:—

(*a*) Change of Dimensions and Stresses of Solids, and of Volume or Pressure of Fluids.
(*b*) Change of Molecular State.
(*c*) Change of Temperature.
(*d*) Electric Effects.
(*e*) Chemical Changes.

Let us consider these in order.

(*a*) CHANGE OF DIMENSIONS AND STRESSES OF SOLIDS, AND OF VOLUME OR PRESSURE OF FLUIDS.

As a rule, bodies expand by heat, but there are many notable exceptions. It is a matter of very great consequence, therefore, to know the laws of expansion; as they are not only indispensable for the scientific purpose of measuring temperatures, but also for many of the most practical operations of ordinary life.

The *co-efficient of Linear Dilatation* of a solid at any temperature is the per centage increment of its length when raised to a temperature one degree higher.

In isotropic bodies, such as glass, lead, &c., this co-efficient is practically the same in all directions. In non-isotropic bodies, such as fibrous wood or iron, and crystalline substances of any but the regular system, it has different values in different directions—all referable, however, to three principal directions at right angles to one another. In these there may even be expansion in one or two, and contraction in the others, or the other. Hence an intermediate direction might be found in which there is no change of length. This was long ago suggested by Brewster for the construction of an invariable pendulum. But the exact determination of dilatation of solids is absolutely essential for the comparison of standards of length, for the measurement of the base-lines for an Ordnance Survey, for compensation pendulums, and for many of the most delicate of physical investigations.

Instruments for determination of the Co-efficient of Linear Dilatation of a Solid in any direction. [Roy, Ramsden, Lavoisier and Laplace, Fizeau, &c.]

The Co-efficient of Cubical Dilatation of a Solid is the sum of its three principal co-efficients of Linear Dilatation:—in Isotropic bodies it is therefore three times that of Linear Dilatation.

Instruments for measuring the *Relative*, and thence the *Absolute*, Dilatation of Liquids.

As measurements of the Volumes of Liquids require that they

should be inclosed in solid vessels, themselves alterable in volume by heat, the determination of absolute dilatation of a liquid requires in general a knowledge of the cubical dilatation of the containing vessels.

The Pressure of the *Ideal Perfect Gas* at constant volume is proportional to the absolute temperature. There are various modes of measuring the pressure of a gas at constant volume in terms of the temperature-indications of ordinary thermometers.

Co-efficient of Cubical Dilatation of a Gas at constant pressure. [Rudberg, Magnus, Regnault, &c.]

Contraction, by heating, of stretched India-rubber, of water between $0°$ C and $4°$ C, of iodide of silver, and of various other anomalous bodies.

(*b*) CHANGE OF MOLECULAR STATE.

The usual agent in all melting, boiling, evaporation, and dissociation is certainly Heat—though, under peculiar circumstances, pressure is found to produce very singular analogous effects.

MELTING OF SOLIDS.

The pressure remaining the same, there is a definite melting point for every solid; and (provided the mass be stirred), however much heat be slowly applied, the temperature of the whole remains at the melting-point till the last particle is melted.

This is one of the bases of Black's doctrine of *Latent Heat.* Our modern knowledge that heat is not matter leads us to regard the energy which disappears to the thermometer as being employed in tearing asunder the particles of the solid. But the first clause of the statement leads to the important question of the influence of pressure upon the melting point. This was first discussed by James Thomson, in 1849, and his calculations with regard to the lowering of the melting point of ice by pressure were exactly verified experimentally by Sir W. Thomson in the same year. Hopkins, Bunsen, and others, have since extended the experi-

mental verification to the elevation of the melting points of substances which *expand* on becoming liquid.

Connected with this, and probably to be completely explained by it, are the curious facts of so-called Regelation, &c., and the whole theory of the motion of glaciers. [Forbes, Faraday, Dolfuss-Ausset, J. Thomson, &c.]

Evaporation of Liquids.

The pressure remaining the same, there is a definite boiling point for the free surface of every liquid; and (provided the mass be stirred), however much heat be applied, the temperature of the whole remains at the boiling-point till the last particle is evaporated.

The effect of pressure upon the boiling point can be calculated, as was that of pressure upon the melting point; but as we do not know of a substance which (at the same temperature and pressure) occupies less bulk in the form of vapour than in that of liquid, we may assert that the effect of pressure is in all cases to *raise* the boiling point. The boiling point of water has been employed to supersede the barometer, as in the Hypsometric Thermometer (Wollaston).

Other instruments depending on these principles are Papin's Digester, The Cryophorus, Daniell's and Regnault's Hygrometers, &c.

Joint Effects of Pressure and Temperature on Fluids.

Liquefaction of gases by Cold or Pressure, or by Cold and Pressure. [Faraday, Thilorier, Natterer, &c.]

The Cagniard-de-la-Tour State.

Andrews' discovery of the *Critical Temperature*, and of the continuity of the Liquid and Gaseous States.

Explanation of the non-condensibility of Hydrogen, Oxygen, Nitrogen, Carbonic Oxide, and Marsh-gas.

Modification of the Critical Temperature by admixture of a non-liquifiable gas. [Andrews.]

Apparatus for measurement of Latent Heat. [Black, Crawford, Irving, Regnault, &c.]

(*c*) Change of Temperature.

Specific Heat.

Various forms of Calorimeter. [Black, Wilke, Regnault, Bunsen, &c.]

Specific Heats of Air and other Gases at Constant Volume and at Constant Pressure.

Methods of Joule and Regnault.

Velocity of Sound.

Tone of Organ-pipe filled with different gases.

(*d*) Electric Effects.

Electricity produced by heating Crystals, &c. [Haüy, Hankel, Thomson, &c.]

Electric currents produced by unequal heating in non-homogeneous circuits. Thermo-electricity.

When one of the junctions of a closed circuit of two metals is raised to a higher temperature than the other, a current of electricity passes round the circuit and increases in intensity with increasing difference of temperature of the junctions. The direction of the current is, of course, reversed if the cold junction be now made the hotter. [Seebeck.]

In certain cases, as in circuits of iron-copper, iron-silver, iron-gold, &c., the current increases more and more slowly for successive equal increments of temperature difference of the junctions, attains a maximum, gradually diminishes, and finally is *reversed* in direction. [Cumming.]

When a current of electricity from an external source passes through a junction of two metals, it causes an absorption or disengagement of heat. If the direction of the current be the same as that which would be produced by heating the junction, the result is absorption. [Peltier.]

Thomson showed theoretically that the Peltier effect is insuffi-

cient to explain the phenomena discovered by Cumming, and that a current of electricity in an unequally heated conductor must, in general, produce absorption or disengagement of heat, according as it passes from hot to cold parts, or from cold to hot. He verified experimentally that this "Electric Convection of Heat" is positive in Copper and negative in Iron. Le Roux has since made valuable measurements of this quantity.

All the phenomena of Thermo-electric currents can be shown graphically by means of Thomson's Thermo-electric Diagram. When such a diagram is constructed from experiment, it appears that the lines representing (in terms of absolute temperature) the thermo-electric position of a metal are, in general, approximately straight, at least for temperatures within the range of mercurial thermometers. There are, however, at least two marked exceptions—nickel and iron, both highly magnetic metals. These give zig-zag or broken lines: nickel changing its sign about 200°C, and again about 320°C; iron at a low red heat, and again at a white heat. With iron, and certain varieties of platinum in which there is no electric convection, a thermo-electric circuit can be formed, giving a current due *entirely* to electric convection in the iron alone.

III.—Measurement of Heat and Temperature.

The absolute measurement of temperature depends upon Carnot's Cycle, and is in fact involved in the Second Law of Thermodynamics. To make absolute temperature measurement agree as nearly as possible with the indications of the air-thermometer, W. Thomson *defined* the ratio of the absolute temperatures of the source and refrigerator of a perfect heat-engine as the ratio of the heat taken in to that rejected. The actual determination of the Absolute Zero (*i.e.* the temperature of a body totally deprived of heat), and of the absolute temperatures corresponding to the indications of any particular thermometer, requires, therefore, experiments made under conditions approaching as nearly as possible to

those of a perfect heat-engine. These will be more appropriately treated in VI. below.

Practically, temperatures are measured by thermometers; and there is no difficulty (though there is often considerable trouble) in passing from their indications to the corresponding points of the absolute scale. What is wanted for practical work is something easy to use, and easily reproducible. When great scientific accuracy is required it is necessary to translate the indications of such an instrument into the corresponding absolute temperatures.

THERMOMETERS.

It seems now certain that the first inventor of the thermometer was Galileo, before 1597 (see "Mémoire sur la Determination de l'Echelle du Thermomètre de l'Academie del Cimento," par G. Libri, Ann. de Chimie xlv. 1830). His thermometer was an air thermometer, consisting of a bulb with a tube dipping into a vessel of liquid. The first use to which it was applied was to ascertain the temperature of the human body. The patient took the bulb in his mouth, and the air, expanding, forced the liquid down the tube, the liquid descending as the temperature of the bulb rose. From the height at which the liquid finally stood in the tube, the physician could judge whether or not the disease was of the nature of a fever.

A similar instrument was afterwards used, for a similar purpose, by the physician Sagredo, who, till recently, was regarded as the inventor of the thermometer.

Air thermometers, however, are affected by changes in the pressure of the atmosphere, as well as by changes in the temperature of the enclosed air, and, therefore, unless this disturbing cause is removed or accounted for, the reading of the thermometer is of no value.

Thermometers, containing a liquid hermetically sealed up in glass, were first made under the direction of Rinieri (died 1647),

by Giuseppe Moriani, who, for his skill in glass-blowing, was surnamed Il Gonfia.

Many of the readings recorded by Rinieri are to be found in the Memoirs of the Academy del Cimento, but these were long supposed to have lost their value, as the instruments themselves could not be compared with our present thermometric scale.

In 1829, however, a number of these very thermometers were found by Antinori, and their graduations were compared with those of Réaumur's scale, so that the readings of Rinieri can now be interpreted.

One of the physical researches for which the Florentine Academy employed these thermometers, was to determine whether the melting of ice always takes place at the same temperature. This question they finally answered affirmatively.

The next great step in thermometry was made by Newton, in his "Scala graduum Caloris," in the Philosophical Transactions for 1701, where he proposes the melting of ice and the boiling of water as standard temperatures.

Fahrenheit, of Dantzic, about 1714, first constructed thermometers of which the graduation was uniform. These thermometers were much used in England, and Fahrenheit's graduation is still the most common in English-speaking countries. In Fahrenheit's scale the temperature of melting ice is marked 32°, and that of boiling water 212°.

The Centigrade scale was introduced by Celsius, of Upsala. In it the freezing point is marked 0°, and the boiling point 100°. The obvious simplicity of this mode of dividing the space between the points of reference has caused it to be very generally adopted, along with the French decimal system of measurement, by scientific men, especially on the Continent of Europe.

The scale of Réaumur, in which the freezing point is marked 0°, and the boiling point 80°, is still used for some medical and domestic purposes on the Continent of Europe.

The existence of these three different thermometric scales fur-

nishes an example of the inconvenience of the want of uniformity in systems of measurement.

The thermometers we have hitherto considered depend on the difference of dilatation of a liquid or a gas and the vessel containing it. Other thermometers depend on the difference of dilatation of solids. Breguet's thermometer consists of a thin compound strip of metal consisting of three layers, of silver, gold, and platinum respectively. This strip is curled up into a helix, the silver side being outermost. As the temperature rises the silver expands more than the gold, and the gold more than the platinum, and the helix coils itself up. The lower end of the helix carries an index by which its rotation is made manifest. This thermometer, from its exceedingly small mass, acts very promptly, and is well fitted to indicate sudden minute changes of temperature.

Other thermometric instruments depend on electric phenomena.

The thermometric current was discovered by Seebeck in 1822. The first thermopile, by which the electromotive force in the circuit was multiplied, was constructed by Örsted and Fourier. It is to Nobili, however, that we owe the development of the power of the thermopile as a method of measuring very small changes of temperature, such as those due to the incidence of heat-radiations.

Another way in which temperature may be measured by electric effects is by the increase in the electric resistance of metals when their temperature is raised. On this principle is constructed Siemens' Resistance Thermometer, which is especially useful for determining the temperature of places not easily accessible, such as the bottom of the sea.

A fine platinum wire of considerable resistance is placed in a closed case at the spot whose temperature is to be observed, and is connected by means of thick copper wires with the place where the observer works. A similar wire in a closed case is placed in a vessel of water, and an arrangement is made by which

the electric resistance of these two wires may be compared. The water in the vessel is then heated or cooled till the resistance of the wire immersed in it is equal to that of the wire at the distant station. The temperatures of the two wires must then be equal, and by observing with a common thermometer the temperature of the water in the vessel, we obtain the temperature of the distant station.

(*a*) Thermometers depending upon the relative expansion of a solid and a liquid. [Florentine academicians, Réaumur, Celsius, Fahrenheit, &c.]

Processes of Calibration, and of making, filling, and graduating Mercury, Alcohol, and Ether Thermometers in glass.

Thermometers with liquid SO_2 or CO_2.

Thermometers with protected bulbs to measure temperatures under pressure. [W. Thomson, Miller, Casella, &c.]

Registering Thermometers. [This class is exceedingly numerous, but the perfect form is the photographic one.]

Statical Thermometer. [Cavendish, &c.]

(*b*) Thermometers depending on the relative expansion of a gas and a solid.

Ordinary Air Thermometer. [Galileo, Drebbel, &c.]

Differential Thermometer. [Leslie, Rumford, &c.]

Scientific Air Thermometers—specially those at constant pressure, to prevent the effects of transpiration at high temperatures. [Regnault, Joule, St. Claire Deville, &c.]

(*c*) Thermometers depending on the actual or relative expansion of solids.

Metallic Thermometers. [Breguet, &c.]

Pyrometers. [Wedgwood, Daniell, &c.]

Averaging Thermometers. [Stevenson's "Creeper," &c.]

(*d*) Thermo-electric Pile and Galvanometer. [Nobili, Schweigger, Melloni, &c.]

A study of the thermo-electric diagram shows that when the specific heat of electricity is equal in any two metals at all tempe-

ratures, the thermo-electric current produced in a circuit of these metals is directly proportional to the absolute temperature difference of their junctions. By arranging three metals in a circuit, two of them in multiple arc, it is easily possible to obtain the same result even when the specific heat of electricity has different values in all three.

(*e*) Electric Resistance Thermometers. [Siemens, &c.]

IV.—Sources of Heat.

(*a*) Furnaces.

(*b*) Bunsen Lamps, Blowpipes, &c.

(*c*) Electric arc.

(*d*) Sun heat: burning lenses and mirrors.

(*e*) Chemical Combination. Heat of Combination. [Andrews, Favre and Silbermann, Thomsen, &c.]

(*f*) Freezing Mixtures.

Arrangements for producing cold by Expansion, Evaporation, &c.

V.—Transference of Heat.

Heat may pass from one part to another of the same body, as by Conduction; from one body to another (even through *vacuum*) as by Radiation; or from place to place with one and the same body, or part of a body, as by Convection.

(*a*) Conduction.

We owe our knowledge of the laws of the Conduction of Heat in Solids mainly to Fourier, who first satisfactorily gave the definition of Thermal Conductivity, or Conducting Power, and with it the original and beautiful mathematical methods requisite for its application.

The Conductivity is measured by the number of units of heat which pass, per unit of time, per unit of surface, through an infinite slab of any material, of unit thickness, whose sides are kept at temperatures differing by any assigned amount—say 1° C. The

"Flux of Heat" across a plane unit of area, at any point of an isotropic solid, is thus proportional to the conducting power and to the gradient of descent of temperature per unit of length in the direction perpendicular to the plane of the area.

Apparatus for measuring Conductivity. [Peclet, Biot, Langberg, Forbes, Ångström, &c.]

Apparatus for showing difference of Conducting power in different directions. [De Senarmont, &c.]

Propagation of surface heat downwards into the crust of the earth. [Quetelet, Leslie, Forbes, &c.]

Loss of heat by the earth in consequence of the observed gradual increase of temperature with depth under the surface.

Instruments for measuring temperature in borings, &c.

Applications of imperfect conductors to prevent waste of heat, as Jackets for the Cylinders of Steam-Engines, &c., apparatus for keeping Ice, Solid Carbonic Acid, &c.

(*b*) RADIATION. (See also under Light, p. 121.)

Apparatus for the measurement of Radiant Heat.

Leslie's Differential Thermometer, and its varieties.

Melloni and Forbes, Thermo-electric Pile and Galvanometer.

Thermo-electric arrangements for heat of Moon and Stars, and for comparative temperature of sun-spots and faculæ. [Airy, Lord Rosse, Secchi, &c.]

Apparatus for absolute measure of Radiation.

Apparatus for rate of cooling *in vacuo.*

Pyrheliometer.

Radiometer.

Apparatus for the full comparison of the behaviour of Light with that of Radiant Heat, as to

Interference,
Diffraction,
Absorption,
Reflexion,

Refraction,
Double Refraction,
Polarization,
Circular Polarization, &c. [Melloni, Forbes, &c.]

Apparatus for experimental proofs of the equality (under all circumstances) of Radiation and Absorption for any particular ray. [Stokes, Foucault, Stewart, Kirchhoff, &c.]

Apparatus for experimental proof of Kirchhoff's fundamental proposition that the hotter a body is the more it gives of the lower radiations, in addition to new and higher radiations. [Akin and Griffith, Tyndall, &c.]

(*c*) CONVECTION.

Processes of Hope and Joule for determination of the maximum density point of water.

Joule's Convection Thermometer for the Moon's heat.

Apparatus and Processes for Ventilation, &c.

VI.—TRANSFORMATIONS OF HEAT.

(*a*) Into Work—Heat engines of all kinds.
Air engines,
Steam engines,
Ether or Chloroform engines,
Gas engines, &c.

(*b*) Into Visible Motion and Sound—
Trevelyan Rockers, &c.

(*c*) Into Electric Currents—
Thermo-electric Batteries, &c.

(*d*) Apparatus for determining various points of the theory of heat and of heat-engines—

Calorific effects of the passage of gases under pressure through porous plugs.

Determination of the efficiency of a perfect engine.

Determination of absolute zero of temperature.

Apparatus for the Kinetic theory of gases.

Determination of the deviations of various gases from Boyle's Law.

Apparatus for diffusion.

Apparatus for gaseous friction, &c.

P. G. TAIT.

MAGNETIC APPARATUS.

THE modern science of Magnetism may be said to date from the publication, in the year 1600, of a treatise entitled, "De Magnete magneticisque corporibus et magno magnete Tellure, Physiologia nova" (London, 4to), by William Gilbert, of Colchester, physician. In this work it was for the first time clearly shown that the earth, as a whole, has the properties of a magnet, and, consequently, that the directive action exerted by it upon a compass-needle represents only a special case of the mutual action of two magnets. Before Gilbert's time some important contributions to the accurate observation of magnetic phenomena had been made by George Hartmann, Vicar of S. Sebald's, Nuremberg. In a letter* to Duke Albert of Prussia, dated 4th March, 1544, Hartmann describes some magnetic experiments that he had shown in the previous year to King Ferdinand of Bohemia, brother of Charles V., from which it appears that he was acquainted with magnetic repulsion as well as attraction, and knew that like poles repel, while unlike poles attract, each other; also that he had observed, contrary to the general belief of the time, that, when one end of a compass-needle is stroked with a pole of given kind, it acquires a polarity opposite to that of the pole employed; and further, that he not only knew that the variation of the compass was different in different places, but that

* Printed in extract by Moser (*Dove's Repertorium der Physik*) vol. ii. pp. 129—133. 1838.

he had discovered magnetic dip. All these discoveries were intrinsically of fundamental importance, but they do not seem to have become known to those who might have based further advances upon them; and, consequently, although the merit of their author is none the less on that account, we cannot trace up to them in an unbroken line of descent what is now known in connection with magnetism. On the other hand, Gilbert's work has never been lost sight of, but has been, ever since its publication, the recognised starting-point of accurate magnetic science.

In the absence of hardened steel as a familiar material, natural magnets or loadstones formed the strongest permanent magnets at the disposal of the early experimenters. The general introduction of steel magnets for experimental purposes is due to Servington Savery (Phil. Trans., 1730).

About 1780, Coulomb discovered the quantitative laws of magnetic force, and laid the foundation of the mathematical theory of magnetism which has been built up by Poisson, Green, Gauss, Thomson, and others. After this date, it does not seem that much progress was made in the experimental study of magnetism, until the discovery of electro-magnetism by Arago, in 1820,* put an enormously increased source of magnetic power into the hands of experimenters, and the discovery of magneto-electric

* According to Horner (*Gehler's Physikalisches Wörterbuch,* vol. vi., p. 661, [edit. 1836]) electro-magnets were not generally known in Germany or Holland until 1830, when attention was called to them by Professors Pfaff, of Kiel, and G. von Moll, of Utrecht, each of whom had become acquainted with them through visiting the Physical Cabinet of the London University (now University College, London), of which the late Mr. Watkins, of the firm of Watkins and Hill, was at that time Curator.

Another point which may be mentioned in connection with the history of electro-magnets is that *tubular* electro-magnets, to which attention has lately been called in this country, were made in Germany in 1850, by Römershausen, who found that an external soft iron tube increased the carrying power of an electro-magnet, with an iron core 0·9 cm. in diameter and 8·4 cm. long, 64-fold. Electro-magnets of similar construction seem also to have been known in France for many years, as they are described and figured by Daguin (*Traité de Physique* [edit. 1861] vol. iii. p. 616), by whom they are ascribed to MM. Favre and Kunemann.

induction by Faraday, in 1831, gave them a new method of investigation.

One of the earliest results of the discovery of electro-magnetism was the attempt to use the great forces capable of being developed thereby for practical purposes, as a source of motive power. When it was found that an electric current, circulating round a piece of soft iron, could maintain an intense degree of magnetisation in the iron without its own strength being diminished, very exaggerated expectations were formed in many quarters of the practical results likely to follow from the employment of electro-magnetic engines; and, although Jacobi, in 1840, and Joule and Scoresby, in 1845, published investigations which ought to have put an end to such misconceptions, we still occasionally meet with evidence that they are not altogether extinct.

In 1845, by making use of powerful electro-magnets, Faraday made two of his most memorable discoveries,—namely, first, that, when a ray of polarized light passes through various transparent substances in the direction of magnetic force, the plane of polarization is altered; and, secondly, that susceptibility to magnetic force is a property of all substances, and not, as was previously supposed, confined to iron and a few chemically analogous metals. He showed that, with reference to the effect of magnetic force upon them, all substances may be divided into two classes, one of them comprising those which tend to move in the direction of *increasing* magnetic force, and the other comprising those which tend to move in the direction of *decreasing* magnetic force. Bodies of the former class, of which iron may be taken as the type, he called *paramagnetic*, and he distinguished bodies of the latter class, of which bismuth is the chief example, as *diamagnetic*. Faraday's investigations into the optical relations of magnetism and the phenomena of diamagnetism have been followed up and extended by several experimenters, among whom Verdet, Plücker, and W. Weber may be specially mentioned.

The distribution of magnetism in long thin steel magnets was

investigated experimentally by Coulomb, and the mathematical expression deduced by Biot from his results has been verified for the same case by various subsequent investigators, who have for the most part employed methods depending upon the laws of magneto-electric induction. Chiefly by similar methods, the distribution of magnetism in some other cases has been examined, and investigations have been made into the relation between the degree of magnetisation and the intensity of the magnetising force, as well as into the connection between magnetisation and various other conditions, such, for example, as different kinds of mechanical strain.

An extremely important branch of magnetic science is that which deals with the magnetic properties of the earth. There is no evidence as to the first discovery of the directive properties of the magnet, but the use of a magnetic needle in navigation was certainly known in Western Europe at least as early as the beginning of the thirteenth century. The fact that a compass-needle does not point in the same direction at all parts of the earth's surface was discovered by Columbus during his first voyage, on the 13th of September, 1492.* It has already been mentioned in this article that the same fact was known fifty years later to G. Hartmann, who had observed the compass to point 6° in Rome and 10° in Nuremberg to the west of North. The property of a compass-needle supported at its centre of gravity to "dip," as though one end had become heavier by magnetisation, was also, as has been said, observed by Hartmann; but the first tolerably accurate measurement of the magnetic dip is due to Robert Norman, an English instrument-maker, who in 1576, found the dip in London to be 71° 50′.

Up to Gilbert's time, such observations as these seem to have been regarded simply as throwing light upon the intrinsic properties of the loadstone, or of artificial magnets, but when it was recognised that the phenomena in question were in reality indica-

* Arago's *Meteorological Essays*, translated by Sabine, p. 323.

tions of the magnetic properties of the earth, they gained immensely in interest. Early in the seventeenth century, the variation of magnetic dip with change of geographical position had been discovered by the Jesuit Nicholas Cabœus, who found it to be about 62°, in north latitude 45°, and as much as 72° in London. In 1617 he intrusted a carefully made dipping-needle to one of the missionaries of his Order who was about to proceed to China, and although the missionary died upon the journey, Cabœus learned that the dip had continually decreased as the equator was approached, and, that farther south, as far as the Cape of Good Hope, a greater and greater southerly dip had been observed. The secular variations of dip and declination cannot have escaped notice when trustworthy observations of these elements had been accumulated during a considerable number of years. The daily change of declination was detected in 1683 by Iachard, a Jesuit missionary, in Siam, and the hourly variation of the same element was observed in March, 1722, by the English instrument maker Graham.*

By the end of the first quarter of the present century considerable progress had been made in the construction of accurate instruments for magnetic observations, as well as in the methods of using them, and a large number of careful measurements had been accumulated; but the year 1833 marks the beginning of a new era in the history of terrestrial magnetism. In that year Gauss published his celebrated treatise, *Intensitas vis magneticæ terrestris ad mensuram absolutam revocata*, which not only at once placed a great part both of the theory and practice of magnetic observation on a new basis, but has been the starting-point of the whole system of "absolute measurement," the importance of which is daily getting to be more fully recognised in all departments of physics. Before Gauss's time, many measurements had been made, particularly by D'Entrecasteaux and Humboldt, and by

* The historical statements in this paragraph are chiefly taken from Horner's Article "Magnetismus" in Gehler's *Physikal. Wörterbuch.*

Hansteen, in order to ascertain the force with which a magnetic needle is urged towards its position of equilibrium at different parts of the earth and at different times at the same place. The method adopted in these observations, however, served merely to *compare* the force acting at one time and place with that acting at another. The great advance made by Gauss consisted in showing how to eliminate the effect due to the particular magnet used, and so, instead of merely comparing one place with another, to express the absolute intensity of magnetic force at a given place and time in terms which do not involve reference to any physical magnitudes except the fundamental units of *length*, *mass*, and *time*. Gauss also contributed very greatly to increase the practical accuracy of magnetical observations by the improvements he introduced in the construction of instruments; and especially by the substitution (first suggested by Poggendorff in 1826) of straight divided scales, observed by reflection in a mirror attached to the magnet, for graduated circles, whenever small changes of angular position were to be measured.

In 1836 the Göttingen Magnetic Association was established for the purpose of making, periodically, simultaneous observations of the magnetic elements in different parts of the world, according to a common plan. The yearly volumes of "Results" of this Association, published by Gauss and Weber from 1837 to 1842, will long be consulted, not only for the stores of accurate observations recorded in them, but also for the details which they contain of the most perfect methods yet introduced for the measurement of any kind of physical phenomena. A few years later, chiefly through the exertions of Sir Edward Sabine, Magnetic Observatories, for observations according to the Göttingen system, were established by the Government in several of the British Colonies.

In conclusion, we must not omit to mention the valuable labours of Lamont, of Munich, and Lloyd, of Dublin, in the construction of magnetic instruments; nor to refer to the method

of automatic photographic registration of the variations of the magnetic elements, which was introduced simultaneously, in 1847, by Mr. Charles Brooke and Sir Francis Ronalds, and has long been in continuous use at the principal English magnetic observatories.

G. Carey Foster.

ELECTRICAL APPARATUS.

ELECTRICAL phenomena are usually and conveniently divided into two chief classes; the first comprising those which depend upon the mutual action of bodies while they are in different electrical conditions, and the second including those which accompany the process of electrical equalization. Phenomena of the former class, since they depend on the existence of a particular electrical *state* in the bodies which produce them, are appropriately called ELECTRO-STATICAL; while those of the latter class, which depend upon the occurrence of an electrical *process*, requiring the expenditure of energy in some shape or other in order that it may go on continuously, are called ELECTRO-DYNAMICAL.

I.—ELECTRO-STATICS.

The first condition for the production of any electro-statical phenomenon is that we should have the means of developing the electrical condition.* Instruments for this purpose are commonly called electrical machines.

* Or rather conditions,—for, as is well-known, there are two antagonistic electrical states, so related that a body is never electrified in one way without another body being electrified in the opposite way and to the same extent. It often happens, however, that when a body such as can be employed in our experiments is electrified in one way, the body to which the correlative equal and opposite electrification is imparted is the earth, whose size is so great that its electrical state is not sensibly affected by any amount of electrification that can be produced artificially: in such cases the *apparent* result is the development of one kind of electrification only.

Electrical Machines.

1. *Acting by friction.*—The most familiar of these depend upon the friction of two different substances against each other. One of the substances is usually a plate or cylinder of glass, less commonly of ebonite, to which rotatory motion can be given by a handle, and the other is a semi-solid metal (amalgam) spread upon leather or silk, and pressed against the revolving glass or ebonite. Such electrical machines are too well known to need further description here.

Armstrong's Hydro-electric Machine.—Another example of a machine, of which the action is essentially similar, is Armstrong's Hydro-electric Machine, in which electricity is generated by the friction of water against the sides of a tube, through which it is driven with great velocity by a current of steam.

2. *Acting by electrical induction.*—An electrified body tends to make the electrical condition of all bodies in its neighbourhood approximate towards its own condition, exerting this action most strongly on those which are nearest to it. Thus, if a positively electrified body, A, is brought into the neighbourhood of two insulated (and previously unelectrified) conductors, B and C, each of these becomes positively electrified, in the sense of tending to impart positive electricity to other bodies, as long as A is present; if, however, B is nearer to A than C is, B becomes more strongly positive than C, or the tendency of B to give positive electricity to C is greater than the tendency of C to give positive electricity to B.* Consequently, if B and C touch each other, electricity flows from B to C to an extent depending on the difference between the electrifications of the two bodies, and electrical equilibrium is established between them. If now they are separated from each other, and removed beyond the range of the sensible influence of the body A, they are both found to be electrified, B

* Stated in more technical language, the effect of the body A is to raise the electrical *potential* of all bodies in its neighbourhood.

negatively and C positively, while A remains exactly in the same condition as at first, and therefore capable of producing the same effects upon B and C, or upon other conductors which may be substituted for them, any number of times. The ultimate electrification of the conductor B is greatest when the conductor C, with which it is put into communication, while under the influence of A, is the earth. The ELECTROPHORUS, of Volta, affords an important and familiar example of the practical application of the principle here indicated. The same principle is also applied in Bertsch's Electrical Machine, which is essentially an electrophorus so arranged as to work by a continuous motion of rotation.

By proper arrangements the conductor B, which, in the manner indicated above can be repeatedly electrified in the opposite way to the body A, can be made each time to impart its electrification to another insulated conductor A′, thus electrifying it more and more strongly. By then causing the conductor A′ to act in its turn upon B, B will be electrified in the opposite way to A′, or similarly to the body A. If B when thus electrified is made to give up its electrification to A, this will become more strongly electrified. Thus by letting A and A′ act alternately upon B, and each time making this give up to A′ or to A respectively the electricity it has received while under the action of the other, each of these bodies can be electrified to a greater and greater degree, and will therefore act with greater and greater intensity upon the conductor B, and the other conductor, whatever it may be, with which B is, at each operation, put into communication. This is, in general terms, the principle upon which several instruments of great importance act.

An instrument on this principle, acting by a reciprocating motion, was described by Bennet in the Philosophical Transactions for 1787, and in the following year an improved form, acting by a continuous rotation, was described by Nicholson. Further improvements in detail were afterwards effected by Bohnenberger. These instruments, however, do not seem to have been used as electrical

machines in the ordinary sense. The chief purpose for which they were proposed was to develope an easily recognisable degree of electrification from a charge which was too slight to be directly detected. Employed in this way, however, they were found frequently to give contradictory results. They consequently fell into disuse, and the principle of their construction seems almost to have been lost sight of, until it was revived within recent years in the construction of actual electrical machines by Varley (1860), Holtz (1865), Töpler (1865), and Sir William Thomson (1867, 1868). In the various forms of electrical machines constructed by Holtz, the part which takes the place of the body B, hitherto spoken of as a conductor, is a revolving glass plate; consequently, the electrical interchange between it and the parts which represent A and C can only affect the portions of it which successively come into actual communication with them.

In all machines of the class here referred to, as well as in the electrophorus, a limited initial charge of one kind is sufficient to develope an indefinite amount of positive and negative electricity. It is to be observed, however, that this is obtained at the expense of mechanical energy employed in maintaining the motion of the machine in opposition to electrical attraction and repulsion, according to the well-known law that there is an increase of electrical energy when work is done against electrical forces.

Besides the methods indicated above for developing the electrical condition, many other processes are known whereby a similar result can be produced. Of these, the contact of heterogeneous conductors, in conjunction with chemical action, as in the voltaic battery (Volta, 1800), or in conjunction with difference of temperature, as in the thermo-electric battery (Seebeck, 1823), and the movement of electric conductors in a magnetic field, or the variation of the strength of a magnetic field in which there are stationary conductors (Faraday, 1831), are those which have hitherto been of the greatest practical importance. Each of these principles has been applied, with very numerous

modifications in the details of the arrangements employed, but so far no arrangement based upon them has been made as efficient for yielding a great amount as well as a high degree of electrification,—or, as it is commonly expressed, a large quantity of electricity of high potential,—as those founded upon friction or on electrical induction; on the other hand, they are in general more efficient than the latter for the purpose of maintaining the process of electrical interchange on which electro-dynamical phenomena depend.

Electroscopes and Electrometers.

Nearly all the instruments hitherto devised for detecting electrification depend upon the principle that the direction of electric force at any point is the direction of most rapid variation of potential, whence it follows that if an electrified body is at an equal distance from two unequally electrified bodies it will tend to move away from the one whose electrical condition (potential) differs least from its own, and towards the one whose electrical condition differs most from its own: while an electrified body, at unequal distances from two equally electrified bodies, tends to move towards the one to which it is nearest. Bennet's Gold-leaf Electroscope (1787) and Bohnenberger's Dry-pile Electroscope are familiar examples of instruments founded upon this principle. It has been recently shown by G. Lippmann (1873) that the alteration of the tension of the surface separating mercury from dilute sulphuric acid, which accompanies changes in the difference of potential between the metal and the acid, can be made to indicate degrees of electrification at least as slight as those which can be detected by instruments that act by electrical attraction and repulsion.

In Electrometers, the thing that is measured is the difference of potential between two bodies, one of which is often the earth; and the fundamental principle upon which all (except Lippmann's capillary electrometer) depend is that the electric force at any point is equal to the rate of variation of potential in space at that

point. In Coulomb's torsion electrometer,—the instrument by which that philosopher (1785) established the fundamental laws of electric force,—as well as in Dellmann's, Peltier's, and Kohlrausch's electrometers, the indications are proportional to the difference of potential between the body under examination and the earth. In the various electrometers devised by Sir William Thomson, especially in the Quadrant Electrometer, whether as constructed by him or as modified and simplified by Branly, the comparison is usually between two insulated conductors.

Electrical Accumulators and Condensers.

Insulated conductors are needed for the accumulation of electricity. When a conductor, originally unelectrified, is charged with electricity, its electrical potential, or degree of electrification (positive or negative) rises in direct proportion to the quantity of electricity that is given to it. The consequence of this is that the magnitude of the charge which can be imparted to a given conductor is limited in two different ways. In the first place, there is always a practical (if not a theoretical) limit to the electrical potential which can be produced by the electrical machine, or other source of electricity, that is employed to charge the conductor; and when the conductor has received sufficient electricity to make its potential the same as that of the source, it cannot receive any more. Secondly, as the potential of the conductor rises, its tendency to impart electricity to other bodies increases, and hence, if more and more electricity is continually supplied it, the leakage consequent on the imperfectly insulating character of the supports, or due to discharge through the surrounding air, becomes after a time equal to the supply, and then the charge cannot any longer increase. The quantity of electricity which an insulated conductor can receive without having its potential raised beyond a given limit, depends partly on the extent and form of its surface, and partly on the position

and size of other conductors in its neighbourhood. The effect of all these conditions is expressed by the term *capacity*,—the capacity of a conductor being the quantity of electricity that is required to change its electric potential by unity. Hence, in general terms,

the quantity of electricity in a conductor = its electrical potential × its electrical capacity.

It follows that, when a conductor has been charged up to the attainable limit of potential, the amount of the charge can be increased only by increasing its capacity, or, in other words, the ratio of the quantity to the potential of the charge. The most effectual way of doing this is to place another conductor near the one that is to be charged, and to give it a charge of the opposite kind to that of the latter. This is done in the instruments known as ELECTRICAL CONDENSERS and ACCUMULATORS, of which the Leyden jar is the most familiar example. In this apparatus the conductor to be charged is a sheet of tinfoil pasted on glass, a second piece of tinfoil being pasted opposite to it on the other side of the glass. To charge the first sheet, say positively, it is connected with the prime conductor of an electrical machine, and the second sheet of tinfoil is connected (either directly, or through the earth) with the rubber of the machine: or, if any other source of electricity is used, the two sheets of tinfoil—or "coatings," as they are usually called—are connected with the parts which correspond with the conductor and rubber respectively. The negative electrification of the second coating then diminishes the positive potential due to the positive charge of the first coating, and *vice versâ*, so that when the full difference of potential, which the machine employed is capable of producing, has been established between the coatings, the quantity of electricity accumulated in each of them is many times as great as that which it would have received in the absence of the other.

When the limit of the charge which can be given to a conductor

is determined, not by the want of perfect insulation, but by the low potential of the source from which it is electrified, the same method of increasing the quantity of electricity received by it can be employed; and by removing the second and oppositely charged conductor, after the conductor to be charged has been disconnected from the source, the potential of the latter may be raised so as greatly to exceed that of the source. Apparatus with a movable second conductor arranged for use in this way, are called *electrical condensers*. The condenser seems to have been first described by Volta in 1782.

It will be seen from what is said above that *quantity of electricity*, *capacity*, and *difference of potential* are so related that if in a given case two of the three are known, the third is at once determined. Consequently the instruments required for measuring these quantities cannot be separated from each other. Among the most important may be mentioned *absolute standards of capacity*, that is, insulated conductors whose capacity is known from their dimensions—the simplest is a metallic sphere at a great distance from any other conductors; *relative standards of capacity*, or accumulators whose capacity has been determined in terms of a known absolute standard; *accumulators, or condensers whose capacity can be varied* at will, and by known amounts. Examples of these are afforded by Sir William Thomson's *platymeter* and various adjustable accumulators formed by the combination of two or more separate accumulators. Other instruments required in connection with these are *electrometers for absolute and relative measurements* of differences of potential, and *standards of difference of potential*, such as the standard element of Mr. Latimer Clark.

Connected with the measurement of capacity is the study of the condition of an insulating medium which separates two oppositely electrified surfaces. It was first shown by Faraday (1837) that the capacity of an accumulator depends not merely upon the size and conformation of the conducting surfaces, but also on a property of the insulating medium between them which he called its

Specific Inductive Capacity. This property has since been investigated by various experimenters, and notably by Boltzmann. Within the last twelve months it has been shown by Kerr, of Glasgow, that the property of optical double-refraction is developed in insulating solids and liquids when a difference of electrical potential is maintained between opposite surfaces. Another important matter connected with the properties of insulating media under these circumstances is the difference of potential required to make a discharge of electricity take place through a layer of given thickness. This has been investigated as yet chiefly by Riess, Rijke, and Sir William Thomson.

The phenomena accompanying the discharge of accumulated electricity, and the effects due to it, belong strictly to the subject of electrodynamics. The following may be mentioned as some of the chief points that have been investigated in connection with the discharge: the appearance presented by it in air or in other gaseous media at various pressures, when viewed either with the naked eye or through the spectroscope; the duration of the electric spark; its heating action; its oscillatory character; and its mechanical effects.

II.—Electrodynamics.*

If two insulated conductors A and B, at different electrical potentials, are connected by another conductor, they very quickly assume a condition of electrical equilibrium characterised by uniformity of potential throughout the system formed by them and the connecting conductor. During the short period occupied by the process of electrical equalisation, the connecting conductor exhibits special properties, not possessed by it under other circumstances, which are usually summed up in the statement that it is

* By many writers, especially on the Continent, this term is restricted to the part of the subject which deals with the mutual force acting between conductors traversed by electric currents; it is here used to include the whole of the branch of electrical science which deals with the effects of electricity in motion.

traversed by a current of electricity. If by any means the difference of potential between A and B can be maintained constant, notwithstanding their being connected by another conductor, this conductor exhibits permanently the special properties which, in the case first supposed, it exhibited only momentarily. In this case a condition of dynamical equilibrium is maintained, as long as the conditions remain unchanged, which is expressed by saying that the conductor conveys a constant electric current, or that an equal quantity of electricity passes any transverse section of it in each unit of time.

The first conditions requisite for the production of any electro-dynamical phenomenon are therefore the existence and maintenance of a difference of potential between two points; and, secondly, a conductor connecting these points in which the difference of potential can give rise to an electric current.

The apparatus which is generally most convenient for the former purpose is some form of *voltaic battery*, *thermo-electric battery*, or, when a rapid succession of currents of short duration or of currents in opposite directions is admissible, *magneto-electric machine*, or *induction-coil.* Ordinary electrical machines may be used with advantage in special cases, but, although capable of producing great differences of potential between insulated conductors, the difference of potential which can be maintained by means of them between the extremities of a good conductor is much less than that which can be kept up by the instruments previously named.

The general construction of the voltaic battery is well known. Of the countless modifications that have been introduced, or at least proposed, none, since Daniell (1836) showed how to make "constant" batteries, are of a fundamental kind; several considerable improvements, however, have been made in recent years in matters affecting the practical convenience of voltaic batteries and their adaptation to special purposes. Similar remarks are applicable also to recent modifications in the construction of thermo-electric batteries.

In the case of magneto-electric machines, changes of construction, which are of a more fundamental nature, have been made within the last few years. The first magneto-electric machines were made in 1832 (by Pixii and by Dal Negro) almost immediately after the announcement by Faraday of his discovery of *magneto-electric induction*, that is to say, of the production of an electric current in a conductor forming a closed circuit, when an alteration takes place in the total magnetic force acting through the area bounded by the circuit. It is evident that such an alteration can be produced in either of two ways, namely (1), by a change in the magnetic force itself, or (2), by a change in the shape or position of the circuit. The first is the principle applied in the *induction coil*, and in some magneto-electric machines, including that of Pixii; the second is that on which the action of most magneto-electric machines chiefly depends, though in many of them the two principles are applied conjointly. The first step in the modern improvements of these machines was the introduction by Siemens and Halske (1857) of an arrangement of the "armature" (a piece of soft iron wound with insulated copper wire, by the movement of which between the poles of a magnet the variations of magnetic force acting across the circuit are produced) whereby nearly the whole force of a large number of steel magnets could be utilised. In 1866 Wilde showed that enormously increased effects could be obtained by causing a Siemens's armature to revolve between the poles of a large electro-magnet, the magnetism of which was developed by the current of a smaller machine provided with permanent steel magnets. In the same year, S. A. Varley, and in the following year, Siemens and Wheatstone almost simultaneously constructed machines in which permanent magnets were entirely dispensed with, and the current caused by a very feebly magnetized electro-magnet was made to strengthen the magnetisation of the magnet which produced it, and so in turn to cause a stronger current whereby still greater magnetisation was developed, and so on, until the resistance of the con-

ductors and the increased power needed to drive the machine prevented any further increase of effect. All the machines yet referred to give—not a continuous current—but a rapid succession of currents in opposite directions, the direction being reversed twice during each rotation of the armature. In 1871 Gramme produced a machine which gives, in the course of one revolution of the armature, any number of successive currents of short duration all in the same direction. In this machine, a soft iron ring rotates, about an axis perpendicular to its plane, between the poles of a magnet, so that one of its diameters always coincides with the line joining the poles. This ring is wrapped with a coil of insulated copper wire, each turn of wire being in a plane containing the axis of the ring, and the ends are joined together so as to make a continuous circuit. At frequent equal intervals throughout the coil, branch-wires are connected with it, whereby it can be joined with other conductors. The action of the machine is, in its main features, as follows. The direction of resultant magnetic force between the poles of the magnet and outside the ring is along the line joining the poles, but on entering the substance of the ring, the direction of resultant force spreads out into two semicircular branches, which reunite at the other end of a diameter. Consequently, through a convolution of the coil encircling the part of the ring which at any instant is nearest to one of the poles, the magnetic force is nothing; whereas, after a quarter of a turn of the ring, when the same convolution has come to be half way between the poles, nearly half the total magnetic force of the magnet acts through it. After a second quarter-turn of the ring, the force acting through the same convolution is again nothing; after a third quarter-turn it reaches a second maximum of opposite sign to the first; after a complete revolution it is again nothing. Consequently, in accordance with the general principle of magneto-electric induction stated above (p. 163), a succession of currents is produced in the coil as it revolves. The rotation of the soft iron takes no essential part in the action, as, from symmetry, one part of it is equivalent to another.

In order to make an electric current follow a prescribed path between two conductors which are kept at different potentials, this path must not only be occupied by conducting matter, but this must be insulated by non-conducting matter from any conductors through which the current is not intended to pass. In most cases copper wires form the most convenient channels for conveying a current in a required direction, and the best insulation is obtained by surrounding them with a sufficiently thick stratum of air; but when there is not room for a sufficient thickness of air, as when wires have to be coiled closely together, or when air is altogether excluded, as in the case of submarine telegraph wires, its place may be supplied by a covering of cotton, woollen, silk, gutta-percha, india-rubber, or some other solid non-conductor.

The apparatus employed for detecting the existence of electric currents and indicating their direction are termed *galvanoscopes;* instruments which serve also for measuring the strength of currents are called *galvanometers.* The general principle on which all galvanoscopes and most galvanometers hitherto constructed depend, may be stated as follows:—

A magnet and a conducting circuit traversed by an electric current tend to assume such relative positions that the magnetic force acting across the area bounded by the circuit is a maximum. In applying this principle it must be borne in mind that a conducting circuit traversed by a current whose apparent direction agrees with the motion of the hands of a watch is equivalent to a magnet whose south pole is towards the eye. The condition stated above is fulfilled when the magnetic forces due to the current and to the magnet act in the same direction, and when the whole force of the magnet acts across the area enclosed by the current. The fact that a mutual force is exerted between a stationary conductor traversed by a current and a magnet was discovered by Oersted in 1820, and very soon afterwards (1821) the ordinary form of galvanometer, with a multiplying coil and pair of astatic needles, was constructed almost simultaneously by Schweigger and by Poggen-

dorff. A point of chief importance in the construction of galvanoscopes is that the magnetic force due to the current at the place where the needle is hung should be as great as possible. The arrangement of the conducting wire required to fulfil this condition has been investigated by W. Weber, Sir W. Thomson, and H. Weber. In instruments intended to show rapid changes in the strength or direction of a current it is essential that the moving parts should be of small inertia. In this respect the reflecting galvanometers introduced by Sir W. Thomson are a great advance upon previous forms. The small size of the magnet, which enables a comparatively short length of wire to convey the current many times round it, also causes a great increase of sensitiveness even in the case of currents of constant strength.

Besides galvanoscopes in which a fixed conductor acts on a movable magnet, instruments have been constructed in which a fixed magnet acts on a movable conductor. The earliest of these appears to have been the *gold-leaf galvanoscope*, an exceedingly sensitive instrument, described by Cumming (see his "Electrodynamics," p. 177 : 1827), which consisted of a strip of gold-leaf suspended between the poles of a horse-shoe magnet and made a part of the circuit in which the current was to be detected. More recently, the same general principle has been applied by Sir W. Thomson in his "Siphon Recorder."

The principle usually adopted in the construction of galvanometers for *measuring the strength* of electric currents, is to place a measured length of the circuit in an accurately defined position with respect to a magnetic needle, and to estimate the force exerted by the current on the magnet from observations of the angular deflection of the magnet from its position of equilibrium, combined with a knowledge of the intensity of that component of the earth's magnetic force which is effective upon the magnet. The best-known types of such instruments are the *tangent-galvanometer* and *sine-galvanometer* of Pouillet (1837). In Ritchie's *torsion-galvanometer*, and in some instruments since constructed on the

same principle, the force between the current and the magnet is estimated from the amount of torsion of an elastic fibre required to balance it.

Galvanometers, in which the effective distance of the conductor from the magnet cannot be ascertained by direct measurement, can be used for absolute measurements if the value of their indications has been determined by comparison with a galvanometer of known dimensions.

The strength of a current can also be deduced from the force exerted between two measured lengths of the circuit, occupying determinate relative positions. Instruments acting on this principle are commonly called *Electrodynamometers*. The first was constructed by Weber (1846). The law established by Faraday (1833), that, when an electric current traverses a compound conducting liquid, chemical decomposition takes place in a quantity of the liquid which is proportional to the quantity of electricity transmitted, is the basis of the so-called *voltametric* system of measuring electric currents.

The strength of the electric current traversing a given conductor depends upon the material and dimensions of the conductor, and upon the difference of potential between its extremities. Stated generally—

*the strength of an electric current in a conductor = difference of potentials between its extremities × its conducting power.**

* It is generally more convenient to express the effect of the dimensions and material of a conductor upon the strength of a current conveyed by it by speaking of its electrical "resistance," rather than of its "conducting power." Conducting power is the reciprocal of resistance, and is used in the text for the sake of bringing out more clearly the electrostatic analogy referred to in the next line. The greater convenience of statements of resistance, as compared with statements of conducting power, arises from the fact that, in practical electrical problems, the addition and subtraction of resistances occurs oftener than the addition and subtraction of conducting powers; moreover, the term conducting power seems to suggest that electrical conductors possess some positive property, by virtue of which they are able to cause a transfer of electricity, whereas the more correct conception probably is that they do *not* possess any property which enables them to *prevent* the transfer.

It will be observed that this relation is exactly parallel to that stated above (p. 159) between the quantity of an electric charge, and the potential and capacity of an insulated conductor, and, just as in that case, so here, a measurement of any two of the three related qualities gives indirectly the value of the third. The above relation, however, taken alone, would afford only comparative measurements of the quantities involved; but by combining it with that which connects the *work* done by a current in a conductor with the electrical conditions of the conductor, namely—

the work done in unit of time between any two points of an electric circuit = strength of the current × difference of potential between the given points,—

the three electrical magnitudes, strength of current, difference of potential, and conducting power, can be expressed in terms of the units employed for the measurement of work,—namely, the units of length, mass, and time, and are then said to be expressed in absolute measure. The introduction of absolute measures into electrical science is due to W. Weber.

The principle of the methods available for the direct measurement of currents has been already pointed out. An absolute standard for the measurement of difference of potential may be founded on the principle that, when (the whole or any part of) a conducting circuit is moved, in such a way as to cause an alteration in the magnetic force acting through the area bounded by the circuit, an "*electromotive force*,"—equivalent to a difference of potential,—is generated, whose value at any instant is equal to the rate at which the magnetic force through the area of the circuit is then varying. A difference of potential produced in any other way may be compared with such a standard by various methods, of which those most generally applicable are adaptations of a method given by Poggendorff, in 1841. An absolute measure of the resistance of a conductor is given by the ratio of the difference of potential (or electromotive force) acting in it to the current produced, this ratio being expressed

in terms of the corresponding absolute units. Here, again, an absolute standard having once been established, other resistances can be measured in terms of it in various ways. The comparison of resistances is most frequently effected by means of some form of the arrangement known as "Wheatstone's Bridge" (first used by S. H. Christie, 1833; more fully described by Wheatstone, 1843), the principle of which is, that the resistances of conductors, traversed by the same current, are proportional to the differences of potential between their extremities. For the purpose of such comparisons, besides an original standard and trustworthy copies of it, conductors are required having resistances which are definite multiples or submultiples of that of the standard, and so arranged that any one or more of them can be readily added to, or removed from a conducting circuit.

In connection with the methods that are available for the measurement of the fundamental magnitudes dealt with in electrical science, it is important to point out that, in some cases, a given electrical magnitude—say a quantity of electricity—can be measured by methods which differ not only as to the apparatus employed and the nature of the observations made, but also in respect of the physical principles upon which they are based. Thus, in electrostatics, a quantity of electricity is estimated (directly or indirectly) by the electric attraction or repulsion it can exert at a given distance, and that quantity is taken as unity, which exerts, upon another equal quantity at unit distance (one centimetre), a force equal to unity (one dyne); whereas, in electrodynamics, the unit of electricity is the quantity which passes any transverse section of a conductor when a current of unit strength flows in the conductor for a unit of time (one second). The electrodynamic measurement of a quantity of electricity thus depends upon the measurement of the strength of a current, and this again is based (directly or indirectly) upon the magnetic force exerted by the current in its neighbourhood, the unit of current-strength being the strength of a current which, if flowing for unit distance along the

circumference of a circle of unit radius, produces a magnetic force equal to unity at the centre of the circle. Now when the same quantity of electricity is measured, on the one hand, by a method based on electrostatic phenomena, or, on the other hand, by a method based on electromagnetic phenomena, it is found that the numerical value obtained in the former case is, in round numbers, 3×10^{10} (thirty thousand million) times as great as the numerical value obtained in the second case. In other words, the quantity of electricity which is denoted by unity in calculations based on electromagnetic phenomena is nearly thirty thousand million times as great as the quantity denoted by unity when electrostatic phenomena are taken as the basis of measurement. An experimental determination of the ratio between these two units was first made by Weber and R. Kohlrausch (1857); subsequent determinations have been made by Sir William Thomson (1868 and 1873), and by Clerk Maxwell (1869).

A more definite idea of the nature of the relation between these two units of electric quantity may perhaps be derived from the following considerations. Suppose an electrostatic unit of positive electricity to be carried round the circumference of a circle of one centimetre radius with a uniform velocity of v centimetres per second; the effect at the centre of the circle will be the same as if a conductor v centimetres long were wrapped round the circle and traversed by a current conveying one electrostatic unit of electricity past each point of it in one second. But a conductor of length v conveying one unit of electricity per second would produce the same effect as a conductor of unit length conveying v units of electricity per second; therefore, in order that the magnetic force at the centre of the circle may be unity, the numerical measure of the velocity v must be equal to the number of electrostatic units in one electromagnetic unit.

The various effects which a current of electricity can produce represent the various forms under which the work done by it can show itself. It has been already said (page 168) that the work

done in unit of time in the part of an electric circuit lying between two given points is equal to the strength of the current multiplied by the difference of potential between these points. It may be added here that, if the direction of the current is from a point of higher potential to a point of lower potential, work is done *by the current;* whereas, if the current flows from a point of lower to a point of higher potential, work is done *in maintaining the current.* We know, however, that if, starting at any point A of an electric circuit and following the direction of the current, we arrive at a point B of lower potential, we shall, by continuing to follow the current, get back again from the point B to the point A; that is, we shall pass from a point of lower to a point of higher potential. Consequently, since the strength of the current crossing any complete section of a circuit is the same, it follows that the nett amount of work done *by* the current in any part of a circuit is equal to the nett amount of work done in the remainder of the circuit *in maintaining* the current.

The different kinds of work which the electric current can do may be classified as follows:—

A. The work done by a current of constant strength traversing a circuit no part of which undergoes change of position relatively to another part or to any other conducting circuit or magnet is entirely *internal;* that is, it appears within the conductors of which the circuit is made up, in one or other of the following forms:—

(1) As development of heat, in metallic conductors of one material.

(2) As development of heat accompanied by transfer of heat causing inequality of temperature, in metallic conductors not all of one material.

(3) As development of heat together with chemical decomposition, in a conductor consisting of a compound liquid.

B. When the strength of a current varies, or when the position of the circuit relatively to other conductors or to magnets is changed, more or less work may be done in the production of effects external to the circuit in addition to some internal work of one or more of the above kinds. The external work may be of any of the following kinds:

(4) Magnetic induction; that is, the development of the magnetic condition in substances susceptible of magnetism.
(5) Production of induced currents in other conductors.
(6) Production of mechanical work through the motion of magnets or of conductors conveying currents.

The laws according to which the action (1) takes place were first ascertained by Joule (1841). The effect referred to under (2) was discovered by Peltier (1834), and has since been investigated chiefly by Edlund (1870—71). The laws of the chemical action of the current (3) were established by Faraday (1833). The magnetising power of the current (4) was first observed by Arago (1820); and the production of induced currents (5) by Faraday (1831). The existence of mechanical force between electric currents and magnets, capable of doing work by changing their relative position, was discovered by Oersted in 1820; and in the same year Ampère discovered that there is a mechanical force between two currents or two parts of the same current. From the laws according to which he found that this force is exerted, he deduced the conclusion that a closed electric circuit has the properties of a magnet, and showed that any magnet might be replaced by a system of circulating currents.

Most of the effects produced by an electric current are connected with the direction of the current in such a way that they are inverted when the direction of the current is inverted. Thus, when a current passes from a piece of bismuth into a piece of antimony, heat is absorbed; but when it passes from antimony to

bismuth an equal quantity of heat is evolved. When a current passes between two platinum plates immersed in water decomposition takes place, and oxygen is evolved at the plate by which the current enters the water, and hydrogen at the plate by which it leaves; inversion of the current inverts the chemical action. Again, a current encircling a piece of soft iron renders it magnetic, and if the current is inverted the magnetisation is reversed. Lastly, if motion is produced by the mutual action of a current and a magnet, or of one current on another, the inversion of the current causes inversion of the motion. The only two cases in which the effect of a current is independent of its direction are the development of heat in a homogeneous conductor, and the force exerted by one part of a current upon another part of the same current. The distinction between the former (reversible) class of effects, and the latter (non-reversible) is connected with the fact that the work expended in a given time in producing any of the former class is simply proportional to the strength of the current, whereas in the case of the latter class of effects it is proportional to the square of the current-strength. A further distinction is that if any reversible effect which a current would produce by traversing a conducting circuit in a given direction, is caused by external agency, a current is generated in the circuit. Thus, by supplying heat at certain points of a circuit composed of alternate pieces of two different metals, and withdrawing heat at certain other points, a (thermo-electric) current is produced in the same direction as that which would have caused heat to be absorbed at the first set of points, and to be evolved at the second set. Again, if the chemical action, which a current in a given direction would produce in a compound liquid, is produced by other means, the result is a current in the same direction provided the liquid makes part of a conducting circuit. Similarly, work done in causing changes of magnetisation in the neighbourhood of a conducting circuit, or changes in the position of magnets or currents relatively to the

circuit, causes the circuit to be traversed by a current opposite to that which would have produced the changes in question. On the other hand, no current is produced by either supplying heat to, or taking heat from, any homogeneous parts of a conducting circuit, nor by moving one part of such a circuit relatively to another part. In fact, all the various methods by which electric currents can be produced, are processes in which some reversible effect of such currents is brought about by the expenditure of external energy.

G. Carey Foster.

ASTRONOMICAL INSTRUMENTS.

ASTRONOMY, so far at all events as instruments are concerned, is an applied science, and the history of practical astronomy is the history of the adaptation of apparatus which had already been used in other fields to the special purpose of studying the heavenly bodies. We begin by measurement of angles, we end with a wide range of instruments illustrating the application of almost every branch of physical as well as of mathematical science. In modern Observatories applications of the laws of Optics, Heat, Electricity, Chemistry, and Dynamics, are met with at every turn.

Each introduction of a new instrument, or of a new method of attack, has by no means abolished the pre-existing one; accretion rather than substitution has been the rule. Measurement of angles goes on now more diligently than it did in the days of Hipparchus, but the angles are better measured, because the telescope has been added to the divided arc. Time is as necessary now as it was in the days of the clepsydra, but now we make a pendulum divide its flow into equal intervals and electricity record it. The colours of the stars are noted as carefully now as they were before the spectroscope was applied to the telescope, but now we study the spectrum and inquire into the cause of the colour. The growth of the power of the telescope as an instrument for eye observations has gone on, although now almost all phenomena can be photographically recorded.

The uses to which all astronomical instruments may be put may be roughly separated into two large groups:—

I. They may be used to study the positions, motions, and sizes of the various masses of matter in the universe. Here we are studying celestial mechanics or mechanical astronomy.

II. They may be used to study the motions of the molecules of which these various masses are built up, to learn their quality, arrangement, and motions. Here we are studying celestial physics, or physical astronomy.

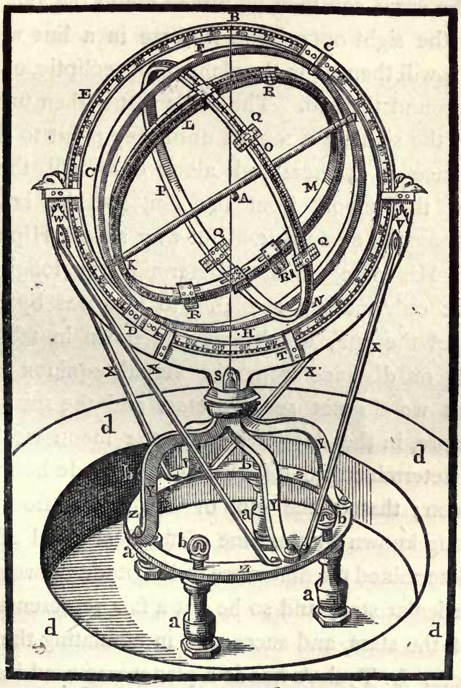
And the instruments may be arranged either to increase the power of the eye or to secure photographic records.

The instrument out of which the instruments comprised in the first group have sprung, dates from Hipparchus (160 B.C.), in whose time divided circles were first used. It consisted of two circles of copper, one smaller and free to move inside the other. The larger one was divided into 360°, and the inner interior one carried two pointers. This was placed in the plane of the meridian, and used for observing the sun's altitude, and was the first meridian instrument. This and the quadrant preferred by Ptolemy to the complete circle, were the parents of mural circles and the transit instruments used in our own day.

It is to Hipparchus himself that we owe the first instrument by which positions could be noted on any part of the celestial vault —"extra-meridional" observations, as they are termed. His astrolabe and other instruments are the foreshadowings of the *Armillæ aliæ Æquatoriæ* and the *Armillæ Zodiacales* of Tycho Brahé, and of the modern altazimuths and equatorials. In the Collection is a model showing, in their most simple form, the principles of the instrument used by Hipparchus for determining either the right ascensions and declinations, or the latitude and longitude of the heavenly bodies, and which enabled him to discover the precession of the equinoxes.

In Tycho's edition of this instrument there is first a large circle, E B C, fixed in the plane of the meridian, having its poles, D C, pointing to the poles of the heavens; inside this there is another circle, F I H, turning on the pivots D C, and carrying fixed to it the circle O P, arranged in a plane at right angles to the points

ARMILLÆ ZODIACALES.



I K, which are placed at a distance from C and D equal to the obliquity of the ecliptic; so that I and K represent the poles of the ecliptic, and the circle O P the ecliptic itself. There is another circle, R M, turning on the pivots I and K, representing a meridian of longitude along which latitude is measured.

This instrument shows, in a very clear way, the great advances made by Hipparchus, who introduced it.

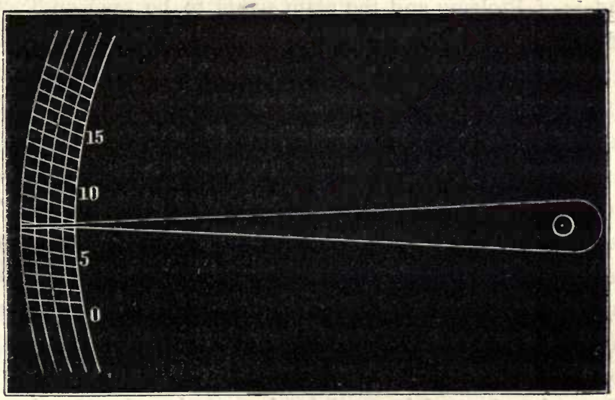
As the sun is in that part of the ecliptic, nearest to the north pole, in summer, its position is represented by the point F on the ecliptic and by N at the winter solstice; so, knowing the time of the year, the sight Q can be placed the same number of degrees from F as the sun is from the solstice, or in a similar position on the circle O P to that which the sun occupies in the ecliptic. The circle can then be turned round the axis C D till the sight Q and the sight opposite to N Q′ are in a line with the sun, the circle O R will then be in the plane of the ecliptic, or of the path of the earth round the sun. The circle R M is then turned on its axis I K, and the sights R R moved until they point to the moon.

The distance Q L, measured along O P, will then be the longitude of the moon from the sun, and its latitude L R, measuring along the circle R M. But why should Hipparchus use the moon? His object was to determine the longitude of the stars, but the only method available to him was by referring to the motion of the sun, which was laid down in tables, so that its longitude or distance from the vernal equinox was always known. But we do not see the stars and the sun at the same time; therefore, in the daytime, while the moon was above the horizon, he determined the difference of longitude between the sun and the moon; that of the sun, or its distance from the vernal equinox, being known by the time of the year; and after the sun had set he determined the difference of longitude between the moon and any particular star; and so he got a fair representation of the longitude of the stars, and succeeded in tabulating the position of 1,022 of them. In Tycho's hands a planet was used instead of the moon, and hence the greater accuracy of his work, which is represented in the Collection by a Quadrant, one of the most interesting relics of past times in the building.

In the vast and admirable collection of instruments brought together by Tycho Brahé were to be found everything the

ingenuity of man had contrived for the observation of the heavenly bodies before the introduction of the telescope. In addition to the *Quadrans Muralis* and the *Armillæ* to which we have before referred we have the *Instrumentum parallácticum sive Regularum*, for measuring altitudes; the *Quadrans Maximus chalibeus quadrato inclusus et horizontí azimuthali chalybeo insistens*, the *Sextans astronomicus trigonicus distantiis rimandis*, and many others.

All these were much larger than the Greek instruments because increased size of instruments were necessary for increased accuracy of reading. Ptolemy read the divisions on his quadrant, which



Diagonal Scale.

was used mainly for observing the height of the sun, by allowing the shadow of a cylinder at its centre to fall on another movable along the divided limb of the instrument. Hipparchus observed within ten minutes of arc. Tycho used plain sights, which were pointed to the object; the circles were divided to minutes of arc, and by using transversals, or a diagonal scale, a method due to Richard Chanzler, according to Digges (*Alæ seu scalæ Mathematicæ*, Londini, 1573), the arc was divided down to ten seconds. This method is well seen in the quadrant formerly belonging to Napier of Merchistoun, contributed by the University of Edinburgh.

It will be seen, then, that great progress had been made in measures of space. Equal progress had been made in the measure of time; for in Tycho's observatory the dial by day and the clepsydra by night had given place to clocks—not clocks as we now know them, regulated by pendulums, but clocks controlled by the oscillations of weighted bars, such as the Dover clock.

The introduction of the refracting telescope and pendulum, in the 17th century, marks the most important epoch in the history of astronomical instruments.

In mechanical astronomy the use of a telescope, instead of the cylinders of Ptolemy and the plain sights to be seen on Tycho's quadrant and on the various astrolabes, at once placed the determinations of positions, and therefore of motions, which are simply changes of position, on a new basis. Nor was this all. In the telescope itself, at the common focus, was soon placed, independently by Huyghens and Gascoigne, and afterwards by the Marquis Malvasia, an apparatus for measuring small angles. The difficulty of doing this, without such an apparatus, is very strongly indicated by Grant, in his admirable History of Physical Astronomy, who tells how Tycho had been so misled by his measurements of the sun and moon, that he had come to the conclusion that a total eclipse of the sun was impossible.

The strip of metal inserted in the eye-piece by Huyghens, is now represented by the modern micrometer, which allows measurements to be made to the hundredth of a second of arc.

Since the time of Hall and Dollond (to which reference will be made further on) refracting telescopes have been constantly growing larger, more perfect and more compact; at the same time the division of the circle into equal parts has been growing more perfect and more minute. Hence the tables are turned, and instead of a small sight on a gigantic arc, we have a large sight (the telescope) on a comparatively small circle. This state of things has necessitated a change in the method of mounting. The telescope is now the first thing to be considered, and it is generally

supported on a central axis at right angles to its length, with carefully finished pivots, which rest on supports called Y's, and the circle which is attached to one end or other of the axis is read by microscopes armed with micrometers. Such an instrument can be well studied by means of the model of the transit instrument at Greenwich (No. 1,780). A vertical circle only is required for transit instruments and prime vertical instruments, but where azimuths are also required, the system, as above described, is made to rotate on a vertical axis, and there is a horizontal circle similar to the vertical one. Dr. Bruhns' Transit Instrument (No. 1,770) shows how the introduction of the use of a prism in front of the object glass affects this method of mounting, and indicates a new method which is certain to be largely used in the future.

The most perfectly-mounted instruments, however, would be almost worthless, for the purposes of mechanical astronomy, were the positions which they determine not accompanied by an accurate statement of the time of the observations. There is ample material in the Collection to show that this is now possible.

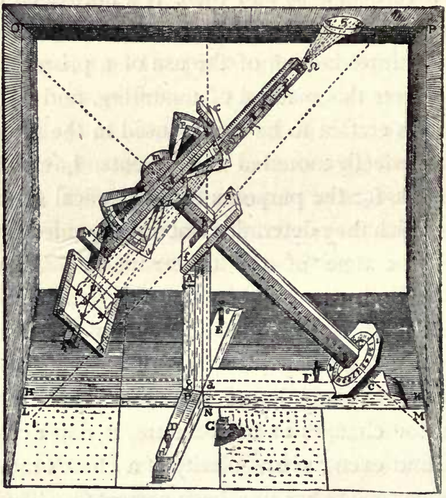
The rude clocks of the Tychonic period have now been replaced by time-keepers only just short of absolute perfection; the compensation of the pendulum o the clock or the balance of the chronometer, for changes of temperature, is now accomplished in various ways, and even the irregularity of a clock's rate for changes of atmospheric pressure has now been corrected. This perfect flow of time, moreover, is now electrically recorded in a permanent manner by means of chronographs (No. 1,843), and the "eye and ear" method of judging of small intervals, by mentally dividing the intervals between the beats of a seconds pendulum into tenths, is now superseded by another, which enables us to record permanently, as accurately as anything human can, any instant or interval of time on a scale which may be as large almost as we please. If observers were infallible, a thousandth of a second would now be a gross quantity (Nos. 1,871—5).

By the introduction of electricity not only can the beats of a

pendulum be permanently recorded, but the beat of a standard clock may be made to control the beats of others (No. 1844).

When we pass from the mechanical to the physical side of astronomy, the means of getting a great quantity of light, and of utilising it in various ways, are the first things to be considered.

In this place, of course, we can only consider this question from the instrumental point of view. We need not enter into the ques-



The Telescope, as used in Galileo's time for observing the Sun.

tion of the actual invention of the refracting telescope. It is quite clear, however, that Galileo, whose instrument has been forwarded from Florence for exhibition, was the one who used it in the very early days with the greatest amount of success. In his time we find it composed of an object-glass rarely exceeding one inch in diameter. In some of the lenses used by Galileo himself it did not even reach these dimensions, and it was soon found convenient, in order to correct the chromatic aberration of the glass, to make the focus as long as possible. The first telescopes, therefore, were of the dimensions of walking sticks. The next great advance made

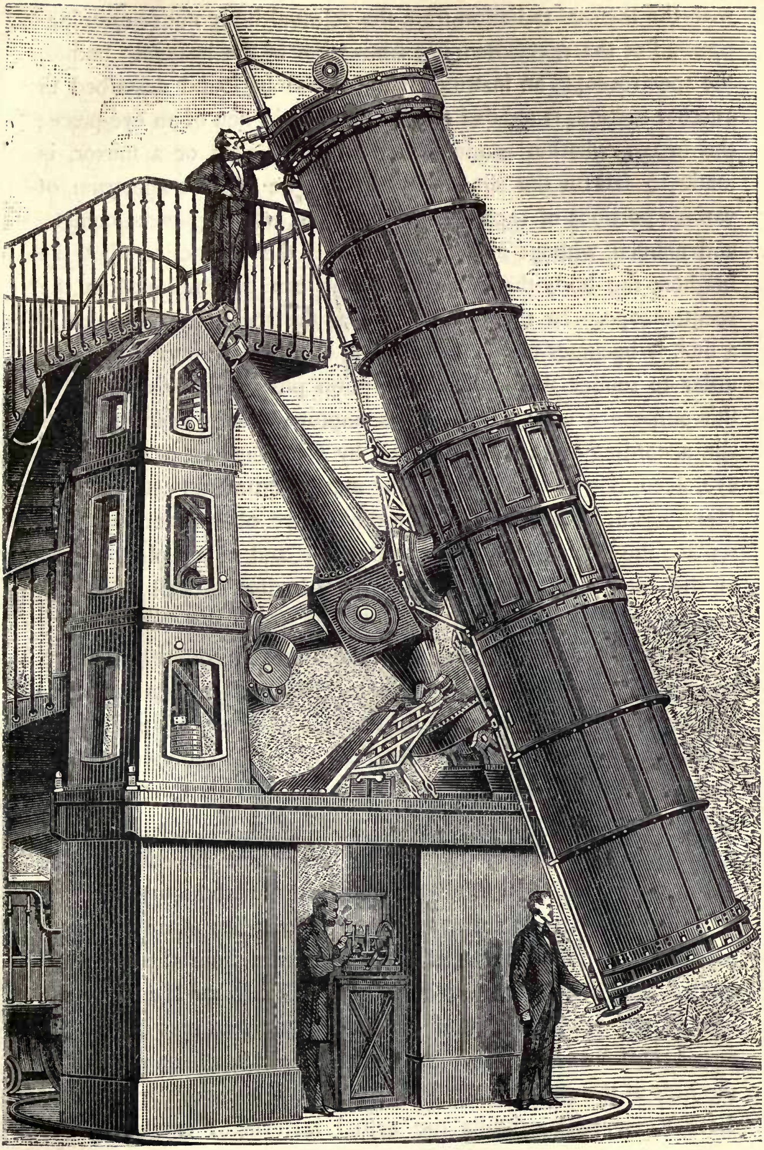
is due to Huyghens, and others about his time, who, still bound by the same necessity of having a long focal length, were, in consequence of the improvements in the manufacture of glass, not bound to the same dimensions. Among the contributions from Holland, and from our own Royal Society, will be seen a large number of lenses, some of them of truly enormous focal length, one of them extending to 360 feet. Although these lenses were made in the infancy, so to speak, of the science, and although they are simple single lenses, the idea of achromatism being one which was introduced very much later, the long focal length, combined with their exquisite figure, makes them astronomical instruments of very great power, although, as they were at first used, it was almost impossible to extract valuable observations from them. The instruments of this kind belonging to the Royal Society, were some years ago erected on a special stage in the Kew Gardens (also among the objects exhibited), and Mr. De la Rue found that the figure was absolutely perfect. Since that time, the introduction of the siderostat, perfected by Foucault, although the idea of its introduction was suggested by Hooke, has afforded another opportunity of judging of their performance, resulting in the opinion of Mr. De la Rue being amply indorsed; and some of them are now being used for the purpose of obtaining enlarged images of the sun, to permit of photographing the disc of the sun, and the spectrum of the various portions.

As is well known, it was the opinion of Newton, who lived in the time of the introduction of these long lenses, that the improvement of this kind of instrument, in the matter of correcting the coloured effects of dispersion, was "desperate;" recourse to reflection was therefore suggested, and as a matter of fact the reflecting telescope dates from Newton's time. Newton's original instrument, by which he demonstrated that by employing a mirror instead of a lens a telescope could be made of a very much more compact form, will be found amongst those exhibited, and also other reflectors made by Sir William Herschel, the late Lord

Rosse, and by the opticians of our own time. Hall and Dollond, however, concurrently with the improvement of the reflecting telescope, showed that Newton's dictum with regard to the refracting one was unfounded, and now the refracting telescope is made as compact, if not indeed more compact than the reflecting one, and with every improvement in the manufacture of glass, the size of the object-glass has been increased; so that now the half-inch aperture of Galileo is represented by the 25-inch aperture of the telescope belonging to Mr. Newall, made by Cooke of York; by the 26-inch apertures of the telescopes recently finished in the United States, by Alvan Clarke of Boston; and by the 27-inch aperture which is now being constructed for the Austrian Government by Mr. Grubb of Dublin, a model of which is exhibited.

Even now, however, the reflector still holds its own in point of size. The 2-inch metallic speculum of Newton was extended to four feet by Sir William Herschel, to six feet by Lord Rosse; to four feet again by Mr. Lassell, and after the introduction of a new chemical process, by which a film of silver of the utmost brilliancy could be deposited on a surface of glass, the heavy metallic speculum, sometimes weighing tons, has now given way to a much lighter and thinner one of glass, which has the distinct advantage of keeping its figure for any length of time, so that now the modern reflecting telescope is perhaps most adequately represented by the 4-foot silver-on-glass speculum of the magnificent equatorial reflector recently erected in the Observatory at Paris.

So much, then, for the means of collecting light. If it is simply intended to use this greater quantity of light for the purpose of increasing the power of the eye—various eye-pieces are used, the construction of which depends upon principles which have been introduced from time to time by Newton, Herschel, Ramsden, Airy, and others. The most interesting applications of the large telescope in our present Observatories are those connected with other uses. Those, namely, which deal with the spectroscopic examination, or the polariscopic examination of light, or, again,



The four-foot Telescope of the Paris Observatory.

with the thermal radiation from the celestial body under examination. For the spectroscopic examination of the heavenly bodies, the spectroscope, an instrument which will be found described in another section, is applied to the telescope in lieu of an eye-piece; the image, whether produced by an object-glass or a mirror, is made to fall on the slit, in which case we get the spectrum of various portions of such bodies as the sun, moon, planets, comets, aud nebulæ without any difficulty, with the distinction that the brighter the body the more dispersion can be employed in the spectroscope. In the case of stars, as the spectrum of a point is a line, it becomes necessary to widen out this line into a band, in order to render the various absorption phenomena visible. For this purpose a cylindrical lens is employed either in front of the slit, according to the method used by Mr. Huggins, or nearer the eye, according to that favoured by many continental astronomers. Here, again, as in the case of ordinary eye observation, we may replace the retina by a photographic plate, and obtain photographs of the spectra of the various heavenly bodies as well as of the heavenly bodies themselves.

The polariscopic examination of the heavenly bodies becomes a point of extreme importance when an eclipse of the sun has to be observed, and we here have a neat means of determining the position in space of the particles which are reflecting the light towards the eye. For this purpose, all that is necessary is to introduce a bi-quartz or a savart, in front of a Nicol in the eye-piece, and the various polariscopic phenomena are seen in this case as they are in the examination of a light source in the laboratory.

The application of a thermo-electric pile in lieu of an eye-piece to determine the amount of heat radiation from the heavenly bodies was, I believe, first employed by Professor Henry in the case of his determination of the various temperatures of the different portions of the sun. Since that time it has been applied to the heat of the stars by Mr. Stone, and to the heat of the moon by Lord Rosse, who exhibits the actual instrument employed, and

there is little doubt that in process of time such an instrument will become part of the regular stock in trade of a physical observatory.

It is impossible, in such a mere sketch as this must of necessity be, to do more than indicate the ground covered by the Collection. The Collection, however, speaks most eloquently for itself, and, thanks to observers in this and other countries, there is no part of the domain, either of mechanical or physical astronomy, which is not illustrated, either by objects of historical interest or by instruments of more recent date, which have aided observations or experiments destined to long outlive those who used them.

J. NORMAN LOCKYER.

APPLIED MECHANICS.

THE science of Engineering, which is another term for *applied mechanics*, has for its aim the "direction of the great sources of power in nature for the use and convenience of man;" and the subjects for illustration are so extensive and varied that it has been thought necessary to limit the present collection to a certain number of selected models and diagrams, which may suggest historical reminiscences of the progress of discovery in this branch of science, and may further prove valuable as indicating the manner in which both the teacher and the student may improve their knowledge of the application of mechanical principles.

And it may be well, in the first instance, to refer to the change which has been wrought within the last few years not only in respect of the nature and scope of the matters necessary to be understood by the student of mechanics, but also in respect of the methods of guidance and instruction which should aid and advance him in his labours.

It is not merely that since the introduction of the steam engine —that masterpiece of inventive genius—new and distinct branches of mechanical engineering have been called into existence which have taxed to the utmost the skill and powers of those engaged in controlling anew "the sources of power in nature;" but it is that a desire for practical knowledge, and for the means of understanding, not the results merely, but the exact manner in which the successive improvers or inventors have toiled step by step up to

the final conclusion, has come to be regarded as so indispensable that no system of abstract thought is received with favour so long as it is not linked with and supplemented by minute observation of the constructive work to which it is related.

Many now living can look back upon the time when a broad line of separation existed between the theoretical and practical mechanician. The former passed his life in the seclusion of the academical retreats of our universities, and thought and pondered and built up a system of study with but little care or regard for the work that was being done by engineers in the world around him, scarcely thinking, perhaps, that it was necessary that the master who had assumed to write for the teaching of others should concern himself with such things as the production of a true plane surface, or the power of measurement, or the invention of machinery for planing iron, or making paper, or printing newspapers, or combing wool, or spinning cotton.

It is interesting to turn to the mechanical treatises written under the old system, and to note that they are to the full as barren and unprofitable as might reasonably have been anticipated from the method on which they proceeded. In style and manner they are faultless; as examples of logical reasoning by symbols they cannot be surpassed; they are full of problems the solution of which demands the highest mathematical skill and aptitude; but unhappily they are the work of men who have remained passive in their own libraries, who have laboured only by the light of their own imagination, who have never seen a pier founded, or a bridge built, or a steam-engine made, and who have considered themselves competent to teach the most practical of all sciences without becoming in any way acquainted with its practice. The result has been that the mechanics of the schoolmen has assumed another and a different form from that by which it is recognised among the mechanicians and engineers who have given us our railways, our steamships, and our telegraphs, and have filled our factories with machinery for supplying all our varied wants.

It is not a little remarkable that the very men who have written so learnedly, but have done so little to advance the progress of general mechanics, and whose failure may be traced to their pursuit of theory without continually recurring to practice and observation, have in one branch which may properly be classed therewith, namely, astronomy, pursued a totally different course, and achieved the most splendid results. In astronomy theory and practice have gone hand in hand. Those who have worked out and completed the marvellous intellectual bequest of Newton have given to their studies a vitality and a force which can only be evolved when the means of observation and the patience to observe move side by side with the advance of the theoretical reasoner.

The prediction of the position of an unknown planet by calculations based upon disturbances which were observed to exist and were previously not accounted for, is a triumph of the intellect which all countrymen of a discoverer contemplate with satisfaction; and here at least no one can say that theory and practice are not in perfect accord. Happily the time is fast approaching when in mechanics, as well as in all other sciences, theory and observation will be inseparably coupled together; and an exhibition such as that now taking place cannot fail to exercise an important influence in confirming and consolidating such a result.

Granted that those who in recent years have invented and developed the machinery of our workshops, that such men as Whitworth, Clement, and Roberts, have laboured without any assistance from abstract theoretical knowledge, and with the help only of their own natural genius in reasoning logically upon what they have observed; granted that the creative minds of Watt, Telford, and Stephenson, although never trained to the study of mathematics, have given us our steam-engines, our canals, and our railways; and it must surely be conceded that there is an enormous field of useful mechanical knowledge in which a man may work successfully for the good of others without being com-

petent to follow the symbolical reasoning of a mathematical treatise. Can it be denied that the principles of mechanics have been understood by those who have shaped and fashioned with their own hands the very subject-matter which gives the science a real existence? And are we not compelled to admit that the path which these men have opened out so successfully may be safely trod by hundreds of the mechanics of our workshops, who will be enabled, when properly guided, to understand and master the solution of many a problem of engineering, and to comprehend many a complicated piece of mechanism, with no further aid than that derived from patient thought upon the principles involved, and a careful comparison of the successive steps which have led previous inventors to the complete and final result?

One object of the present exhibition is to show the manner in which the discoverer has worked, as well as the materials which he has had at his command, and we may now point to a few illustrations. Every one has heard of the model of Newcomen's engine, which Watt undertook to repair, and King's College lends an original fac-simile of Newcomen's engine. There is also an interesting collection presented by Mr. Gilbert Hamilton, of the Soho Works, near Birmingham, which may serve to remind us of the progress of Watt's thoughtful labour in giving a substantial form to his conceptions of the separate condenser and the expansive working of steam. Little more than a hundred years ago, and the manufacturing industry of this great country was yet unborn, though it was destined to spring into existence as soon as the inventive genius of the great mechanic had divined, with such models before him, a better mode of "directing one of the great sources of power in nature."

At that time the machine tools for shaping iron were almost inadequate to the construction of a steam-engine. We are told that the piston in Newcomen's engine was made steam-tight by a layer of water on the top of it, and that in Watt's first engine, which had a cylinder of only eighteen inches diameter, it was

found so difficult to fit the piston accurately to the cylinder that the anticipated success of the first trial was in a great measure defeated. But it is well known that difficulties of this kind exist no longer. A small case in the collection will make this evident, and will indicate the manner in which it has been accomplished. Here will be seen a splendid specimen of a surface plate, lent by Sir J. Whitworth & Co., and many will examine with interest the mode both of constructing and supporting that primary surface upon which we rely in the construction of machinery, being in effect, the closest approximation to an absolute plane surface which has yet been attained.

It might be thought that when a so-called "mechanical true plane" had been produced there was nothing more to be done; but that is only the beginning of the work. By a rapid extension of construction, Sir J. Whitworth made a measuring machine for the workshop which will enable the mechanic to test the accuracy of measurement to the ten-thousandth of an inch, and in the collection there will be found a steel cylinder one inch in diameter, used as a standard measure; and a corresponding collar or internal gauge into which the cylindrical or external gauge exactly fits; a second cylinder of steel one ten-thousandth of an inch less in diameter is placed side by side with the former, and the difference of mechanical fit due to this ascertained difference of size is made apparent at once. But if it be possible to make two exact cylinders differing by such a minute difference of diameter, and, further, to measure this difference by a machine, it is quite clear that our constructive power must have advanced most wonderfully since the days of Watt. In truth it is now equal to the task of producing a machine by which an interval of one-millionth of an inch is made a measurable quantity. We have not space to discuss this matter fully, or to show how much may be learnt from the examination and handling of apparatus of this kind, but it is needful to point out that the power of constructing true surfaces and the power of measurement are the two

things which have combined to give us the machinery of the present day. Thus, a planing machine is an instrument, as its very name implies, for multiplying plane surfaces, and it does this work by transferring to the piece of metal operated on, the truth of guiding plane surfaces formed first of all within itself. The slide-rest of a lathe is built up of plane surfaces sliding upon each other. The bed of a lathe must be a plane, or it would be inadequate for the direction of the slide-rest. The lathe and the planing machine are continually producing and correcting surfaces required for the construction of other machines, and it is, therefore, most necessary that they should themselves be perfect models. Indeed, if we extend our survey beyond the workshop, it will be found impossible to separate our successful manufacturing skill from that primary element on which it is founded, viz., the mechanical power of producing true geometrical forms.

But recurring to the subject of the steam-engine, it is hoped that many objects for the illustration of its working parts, and many diagrams to aid the teacher, will now be brought together. The School of Mines supplies a valuable series, while both Mr. Anderson's and Mr. Shelley's diagrams present much that cannot fail to be useful. We see the first conception of the compound cylinder engine by Hornblower, and can pursue the theory of the expansive working of steam as well as its practice. The application of this principle to marine engineering is a matter of the highest interest, and everything that shows better the mode of carrying it out must be extremely valuable. In the present notice the writer has contended for the greater extension of mechanical teaching by close and exact reasoning upon observed facts; and it may here be well to remark that the development of the mechanical theory of heat has opened out a new region for exploration. In 1872 the annual production of coal in Great Britain was estimated at 120 millions of tons. One pound of ordinary coal develops in its burning a number of units of force, which represent $\frac{1}{4}$ lb. of coal for each

indicated horse-power of a steam-engine per hour. Few engines at the present time produce an amount of work estimated at one indicated horse-power per hour with a less consumption than $2\frac{1}{2}$ lbs. of coal, or about ten times the theoretical expenditure. If the next generation of engineers were to effect a general saving of one half only of the ordinary consumption of fuel for the production of steam power, the gain to the nation would be enormous; and just as the science of telegraphy has advanced under the complete union of the highest mathematical research with the practical experience due to continued observation of experiments, it may be hoped that when theoretical investigators meet their practical fellow-labourers on common ground, such as that now referred to, a new era of progress and discovery may be marked out, having for its aim the wiser and better "direction of one of the great sources of power in nature," namely, the store of energy existing in a bed of coal.

J. M. Goodeve.

CHEMICAL APPARATUS AND PRODUCTS.

SCIENTIFIC chemistry must be considered as somewhat modern: for, although methodical chemical operations have been carried out by man from the earliest times, it is only during the last two centuries that any attempt has been made to group the various facts discovered into a system, and to offer any philosophical explanation of the chemical changes which have been observed.

Doubtless the earliest chemical arts were metallurgical, for the metals, gold, silver, copper, iron, tin, lead, and mercury, were known to the ancients. As gold occurs in nature almost always in the metallic state, either in masses or in particles amongst river sand, it could not fail to attract attention by its brilliancy and high specific gravity, an accident would reveal the fact that it may be melted by heat, and that the smaller pieces could be united. Silver also is often found as metal, the minerals containing it are heavy, and some of them are reduced to the metallic state by the simple application of heat; so that this is probably the second metal which was noticed. Copper occurs native, and some of its ores may be reduced without much difficulty; but iron can only be obtained from its minerals by the employment of considerable metallurgical skill; consequently, we find, from the investigations of ancient tombs, &c., that this latter metal did not come into use until some time after copper or bronze.

The Egyptians seem to have been in advance of other nations

in the art of metallurgy. Besides gold and silver, copper (or brass), iron, tin, and lead are mentioned in the books of Moses, whereas during the Trojan war, some considerable time after Moses, Homer states that swords of bronze were still in use.

Pliny, in his Natural History, written in the first century, describes very carefully many chemical substances, the processes by which they are obtained, and their applications in the arts; treating of the metals, painters' colours, glass, dyeing, calico-printing, soap, starch, beer, stone-ware, and precious stones. His writings are characterized by accuracy, and indicate persevering research. Nevertheless, his statements are sometimes incomplete, which is no doubt due to the fact that in his time a study of the arts was considered to be below the notice of philosophers and others in high station, a failing which has perhaps not entirely disappeared from the society of the present day. Pliny mentions mercury as being well known in his time.

Chemistry was much advanced by the Arabians, who devoted a great deal of attention to the preparation of chemical medicines. They mixed various substances together and submitted the mixtures to the action of heat. In this way many new bodies were formed; and we find that Geber, in the eighth century, was acquainted with the processes of distillation and filtration, with the use of the water-bath, with the mode of purifying common salt. He knew the carbonates of potash and soda, the nitrates of potash and soda, nitric acid, nitrate of silver, sal ammoniac, aqua regia and its power of dissolving gold, alum, sulphuric acid, copperas, borax, distilled vinegar, corrosive sublimate, oxide of mercury, milk of sulphur, several metallic sulphides, arsenic, and white arsenic, and the oxides of copper and iron. He considered the metals to be compounds of mercury and sulphur of various qualities and in different quantities, and it was this belief which made him think it possible by proper processes to convert the metals into one another, thus constituting him the first alchemist.

The influence of the Arabians on chemistry is evidenced by

some of the names still in use, as alembic, alkali, and alcohol, containing the Arabic prefix *al.*

From the time of Geber to the end of the fourteenth or middle of the fifteenth century there seems to have been a succession of philosophers who spent most of their energies in vainly endeavouring to discover a material that would turn all metals into gold, a liquid that would dissolve everything, and a medicine that would prolong life indefinitely. During their wild experiments some very valuable discoveries were, however, made, but most of them were described in such an enigmatical manner that it is extremely difficult to understand their meaning, or, indeed, if they have any meaning at all. The belief in the transmutability of metals existed till the end of the seventeenth century, and even as late as 1721 an alchemical experiment is gravely recorded.

From Geber to Boyle, who has been termed the father of modern Chemistry, many most important isolated discoveries were made, and materials were thus prepared for a comprehensive theory, the use of which was delayed by the prevalence of scholastic speculations.

Towards the close of the seventeenth century, Stahl, who died in 1734, developed, from the suggestions of Beccher, a methodical theory of Chemistry. This was the theory of Phlogiston, which was held by chemists for nearly a century. According to this theory, all combustible bodies contain a peculiar principle named phlogiston, and it is the escape of this principle which causes flame. These chemists showed that the burning of combustible bodies, and the changes which some metals undergo when heated in air (or calcination), are processes of the same order, and Stahl described several experiments which indicated that the escape of phlogiston took place under these conditions. When phosphorus and sulphur are burnt products are formed which when dissolved in water possess the characters of acids, whilst metals, such as lead, zinc, and iron, when submitted to calcination, give rise to earthy bodies called calces. When a calx, such as that of lead, is heated with a combustible substance like charcoal, metallic lead is reproduced; it was

therefore supposed that the phlogiston had left the charcoal to unite with the calx of lead forming the original metal. They found that almost any combustible was capable of effecting this change, and they employed for the purpose other metals, iron and zinc, and other combustibles, sugar, coal, and flour. The process being a general one, it was natural to suppose that the phenomenon was due to the transference of the phlogiston from one body to the other. Boyle had previously shown that during the calcination of tin an increase of weight takes place, which seems at variance with the supposed loss of phlogiston in the process; the phlogistians, however, were equal to the occasion, and ascribed to their subtle principle a property of levity, which explained the fact. They considered phlogiston as a dry substance of an earthy nature, since most combustibles are insoluble in water, a property which was supposed to be common to all earths. The more enlightened followers of this school did not, however, regard the separate existence of phlogiston as necessary: for Bishop Watson, of Llandaff, wrote that a "handful of phlogiston was not to be expected."

The researches on gases towards the end of the last century exerted a great influence on the theory of chemistry. The term gas was first employed by Van Helmont at the beginning of the previous century; but although he seems to have suspected the existence of different kinds of gas, he confused several under the name of *gas sylvestre*, which he says will not support combustion; he states that it is evolved during the fermentation of wine and beer, that it is produced when charcoal is burnt in air, and when marble or chalk is dissolved in distilled vinegar: in these processes we know that carbonic acid gas is formed. But he also gives the name of gas sylvestre to products from other operations which are now known to form the oxides of nitrogen and other gases. About a hundred years later, Dr. Hales published a treatise on various kinds of air; and afterwards the study of pneumatic chemistry was much advanced by the experiments of Black, Cavendish, and Priestley. Black showed that the difference between the caustic and mild

alkalies was, that the latter contained *fixed air*—a kind of air identical with that obtained from fermenting liquids. Black's pneumatic trough and balance are exhibited. Cavendish clearly pointed out the differences between *inflammable air*, which we now call hydrogen, and fixed air, now known as carbonic acid gas. He determined, although not quite accurately, the relative weights of these gases compared with common air, and described several processes by which they may be obtained, and the mode of collecting and experimenting with gases in general. The balance with which these determinations were made has been sent by the Managers of the Royal Institution. In 1774, Priestley (and almost simultaneously Scheele) discovered oxygen gas, which he found supported combustion and life more powerfully than common air. It had been known previously that air in which combustibles had been burnt became incapable of supporting combustion and life, and was hence said to be *phlogisticated*. Priestley, therefore, called his new gas *dephlogisticated air;* common air being intermediate between these two extremes. In consequence of the inflammability and lightness of inflammable air, Cavendish imagined that it was phlogiston itself, and expected that when inflammable air was burnt in dephlogisticated air that the result would be phlogisticated air. On the experiment being tried the gases disappeared, and the sole product was water. Besides oxygen, Priestley discovered and described several other important gases, and improved the apparatus employed for such experiments. The experiments of Priestley on the preparation of oxygen were carefully examined by Lavoisier; and they, together with many of his own discoveries, enabled him to work a complete revolution in the theory of chemistry. Lavoisier showed that when bodies burn, and metals are calcined, the combustibles unite with a portion of the air, and that the metal increases in weight exactly as much as the air diminishes; so that instead of a combustible losing anything when burning, as the phlogistians believed, it actually combines with a gaseous matter from the atmosphere. He showed also that when calces are

reduced to metals by heating with charcoal, a gas is evolved which is identical with that produced by burning charcoal in the air: in fact, the charcoal had combined with the principle that had previously been abstracted from the air during the process of calcination. The new antiphlogistic or Lavoisierian chemistry met with many opponents, and it did not explain the fact, that when metals are dissolved in sulphuric or muriatic acid, a gas which was then supposed to be phlogiston is evolved. He determined to try to discover what was produced by the combustion of inflammable air, when he was informed that Cavendish had found that the product was water. He repeated the experiment on a larger scale, and found approximately that water is formed by the combination of two volumes of inflammable air with one volume of oxygen. He then showed that when steam is passed over red-hot iron, the same inflammable air is produced, and the iron becomes converted into a calx, which can afterwards be reduced like other calces by means of the inflammable air, water being again formed. The materials for a complete explanation of known facts were then at hand. Hydrogen is evolved from metals during solution in acids because water is decomposed, a calx being formed which is dissolved by the acid; and this explanation has been accepted until comparatively recently, it now being believed that the hydrogen is evolved by the decomposition of the acid and not of the water. Lavoisier, noticing that acids are formed when the products of the combustion of carbon, sulphur, and phosphorus are dissolved in water, supposed that oxygen is an essential constituent of all acids, and gave it the name it now bears, signifying the acid producer. Subsequent researches have shown that there are acids destitute of oxygen, and that hydrogen is the element which is always present. The chemical nomenclature was altered so as to accord with this theory, and the system published in 1787 formed the foundation of the one at present in use.

About the same period analytical chemistry was making pro-

gress. Minerals were first systematically analyzed by Bergman at Upsala, the results being published between 1777 and 1780, and the processes were much improved and extended by Klaproth in Berlin, and also by Berzelius. The use of the blowpipe was pointed out by Gahn, who undertook the experiments at the suggestion of Bergman. The careful analysis of minerals led to the discovery of many new elements, and the processes have been undergoing improvement by a succession of chemists until the present hour.

The application of electricity to the decomposition of chemical substances resulted in the discovery by Davy of the metals of the alkalies, potassium, sodium, and lithium, and of the alkaline earths barium, strontium, calcium, and magnesium, and although he failed in the decomposition of alumina, glucina, yttria, and zirconia, they were suspected to be metallic oxides, which was afterwards proved to be the case. Davy also showed that chlorine was not a compound but an elementary body, and the subsequent discovery of iodine and bromine, and the acids that they produce when combined with hydrogen, proved that Lavoisier's notion that oxygen was the sole acidifying principle was erroneous. The balance belonging to the Royal Institution, and used by Young, by Davy, and by Faraday, is in the Collection.

As early as 1699 Homberg showed that equal quantities of an alkali required different amounts of various acids to completely neutralise them. These results attracted little or no attention at the time, and even in 1777, when Wenzel published the results of a careful set of experiments in which he determined the quantities of two pairs of neutral salts that were adequate to decompose one another with formation of two other neutral salts, the minds of chemists were so much occupied with the discussion of the phlogistic and anti-phlogistic theories, that no notice was taken of his work. The fact that many chemists endeavoured to determine the exact composition of salts is evidence of the belief of the constancy of composition of chemical substances. In 1804 Dr. Dalton proposed to explain the uniformity of composition by assuming that

all the elementary bodies are constituted of minute indivisible particles or *atoms*, and that compounds are formed by the union of these atoms. He was led to this idea by the examination of two compounds of carbon and hydrogen called olefiant gas and marsh gas, when he found that the latter gas contained, for the same amount of carbon, exactly twice as much hydrogen as the former; he therefore supposed that olefiant gas was composed of one atom of carbon united with one atom of hydrogen, whilst marsh gas contained one atom of carbon united with two atoms of hydrogen. An interesting collection of apparatus used by Dalton, much of which was made with his own hands, is contributed by the Literary and Philosophical Society of Manchester. In 1808 Gay-Lussac showed that when gases combine there is a very simple relation between the volumes of the constituents and the volume of the product when measured in the form of gas or vapour. Thus, two volumes of hydrogen combine with one volume of oxygen to form two volumes of steam, and two volumes of ammonia consist of one volume of nitrogen united to three volumes of hydrogen. These singularities are now explained by the dynamical theory of gases, which leads to the conclusion that equal volumes of different gases contain equal numbers of molecules. These molecules may be simple or compound, consisting of one elementary atom, or of a number of such atoms.

The constitution of matter has been much elucidated by the study of organic compounds. These are bodies derived from the vegetable and animal kingdoms. Many of them have been long known, but it was not until 1811 that precise analyses of organic bodies were attempted, by Gay-Lussac and Thénard; the processes were afterwards modified by Berzelius, De Saussure, and Prout, and finally brought to perfection by the investigations of Liebig.

The atomic theory was much advanced by the discovery, in 1815, by Gay-Lussac, of cyanogen, a gaseous compound of carbon and nitrogen, possessing many properties analogous to those of the

elementary gas chlorine. Thus the metal potassium burns in cyanogen, producing potassic cyanide, in a manner similar to that in which it burns in chlorine to produce potassic chloride. The discovery of this *compound radical*, as it was called, was followed, in 1842, by that of cacodyl by Bunsen; of butyl by Kolbe, in 1847; and of methyl, ethyl, and amyl by Frankland, in 1849. These bodies differ from cyanogen in being the analogues of another series of elements, of which hydrogen and the metals are types.

Organic analysis soon showed that there were many compounds possessing exactly the same composition, but differing in properties; for example, oil of turpentine, otto of roses, and oil of lemons are bodies containing the same elements, and in the same proportions, although possessing very different properties. Sometimes this may be explained by the fact, that the molecules of these bodies contain different numbers of atoms, when they are said to be *polymeric;* sometimes, however, the molecules contain the same number of atoms, when they are said to be *isomeric*, or *metameric.* This has been explained by the different arrangement of the atoms in the molecules.

In the early days of the study of organic compounds, it was supposed that these bodies could only be produced by vital force, and this opinion was held until 1828, when Wöhler obtained urea artificially. Since that time a large number of organic compounds have been built up from purely mineral matter. This synthesis of organic compounds has been of great service to chemistry, since it has shown that the properties of the products vary according to the manner in which the compounds are produced; isomeric substances being formed when the compounds are, so to speak, put together differently. The study of isomeric bodies and organic synthesis are at present being investigated by a large number of chemists, and amongst the greatest triumphs of organic synthesis is the artificial formation of alizarin, the valuable colouring matter of madder, which was effected by Græbe and Liebermann in 1870.

The researches of Gerhardt and of Williamson upon oxidised

organic compounds, and those of Wurtz and of Hofmann upon organic compounds containing nitrogen, led to the theory of types which regarded the former set of bodies as derived from water, and the latter from ammonia, by the substitution of radicals, or groups of atoms of carbon and hydrogen, for the hydrogen of the typical substances. The extent to which this substitution may be carried is perhaps most conspicuously illustrated by the researches of Hofmann on the ammonia derivatives, by which he has shown that the hydrogen of ammonia may be replaced by other elements and radicals; that the nitrogen may be replaced by phosphorus, arsenic, or antimony; and that in ammonic chloride the hydrogen and nitrogen may be similarly replaced, and the chlorine by bromine or iodine, the resulting bodies possessing the characteristic properties of those from which they are derived. All these results indicate a general similarity of construction of compounds, and this has been considerably elucidated by the doctrine of atomicity. The first indication of this doctrine is contained at the conclusion of a paper on "A New Series of Organic Bodies containing Metals," by Frankland, in the "Philosophical Transactions" for 1852, in which he points out that there is a limit in the power of certain elements in uniting with others. Before this limit is attained the resulting compound is still unsatisfied, and additional atoms can be assimilated, but when the limit is reached the body becomes saturated and incapable of further combination. This doctrine was further extended to the carbon compounds by Kolbe, and the general application by Kekulé of the idea thus originated has enabled chemists, in a large number of cases, to give explanations of the atomic constitution of chemical compounds.

The application of these ideas to mineral chemistry has also been made, notably by Frankland, and the results arrived at, now that the atomic weights of the elements have been altered so as to stand in a simple relation to their specific heats, exhibit a remarkable degree of regularity.

It must not, however, be supposed that we even now possess a complete system; the equation

$$2\,H_2 + O_2 = 2\,O\,H_2$$

shows that 4 vols. of hydrogen combining with 2 vols. of oxygen produce 4 vols. of steam, and also that 4 parts by weight of hydrogen uniting with 32 parts by weight of oxygen form 36 of water; but there is one thing that it does not show, that is, the development of an immense quantity of energy in the form of heat. This the phlogistic theory did indicate, but nothing else. So, as has been pointed out by Professor Crum Brown, the true representation of chemical action is probably contained in a combination of the atomic theory and the theory of phlogiston, if for the term phlogiston we substitute potential energy.

On consulting the works of the earlier chemists it is impossible to avoid being struck by the almost universal employment of fire in their operations; furnaces being described and depicted for large numbers of processes, many of which were carried on for days, for months, or even for years. This is, no doubt, due to the devotion to the study of the metals in the search for the philosopher's stone. The recent progress of organic chemistry and the use of gas for fuel has perhaps been the cause of some neglect of furnace operations, but the invention of gas furnaces giving very constant temperatures will probably direct the attention of chemists once more to the application of elevated temperatures, and a simple instrument for measuring the temperature will materially aid in bringing the processes to perfection.

Specific Gravities of Gases and Vapours.

The close relation existing between the molecular weight of a gas and its specific gravity, renders the determination of the densities of gases and of the vapours of volatile liquids and solids a matter of great importance to the chemist, as he is often able, by

means of the information thus acquired, to fix the exact composition of a body under investigation. All that is necessary is to determine the weight of a known volume of the gas or vapour, but the process of course varies with the condition of the body at the ordinary temperature. If a gas, three processes may be employed. The most accurate one is that employed by Regnault, in which he used a flask, of ten litres capacity, which could be connected by means of brass stopcocks to an air-pump, a pressure gauge and a receiver containing the gas of which the specific gravity was to be determined; the tube between the receiver and the globe being provided with apparatus for thoroughly drying the gas. After the flask was surrounded with ice, it was exhausted by the air-pump and filled with dry gas from the receiver. This process was repeated several times, so as to ensure the purity of the gas in the globe. When the globe was filled and the pressure of the enclosed gas measured, the stopcock was closed, and the flask suspended from the pan of a large but delicate balance, to the other pan of which a globe of equal size was attached. After weighing, the globe was once more surrounded with ice, as much gas as possible pumped out, the pressure of the remainder measured, and the flask again weighed. The difference between the two weighings gave a number, from which the weight of the gas contained by the flask could be calculated. The same series of operations was then carried out with the standard gas (hydrogen or air), and from the results obtained the specific gravity was determined.

This process is extremely delicate and adapted for standard determinations; a simpler one, which can be performed more rapidly, and giving results sufficiently accurate for all ordinary purposes, is that devised by Bunsen.

A third process for the determination of the specific gravity of gases was devised by Bunsen, and is based on the discovery by Graham that the velocities with which gases pass through a minute hole in a thin metallic plate—their rates of effusion—are inversely

as the square roots of their specific gravities. The method consists in observing the time required for the passage of a measured volume of gas through a very fine hole in a platinum plate.

When the specific gravity of the vapour of a volatile solid or liquid is to be determined, the method of Gay-Lussac is usually employed. This consists in introducing a small glass bulb containing a weighed quantity of the substance into a graduated tube inverted over mercury in an iron trough. The tube is then surrounded by a glass cylinder open at both ends, and with the lower edge depressed in the mercury in the trough. Water or oil is placed in the cylinder, and heat applied to the bottom of the mercurial trough. When the apparatus has been uniformly heated to the proper temperature, the volume of the vapour is read off, and by the usual methods of calculation the vapour density is obtained.

Instead of using the iron mercurial trough, it is more convenient to introduce the tube supported by an iron stirrup with a mercury cup at the bottom into a large test tube containing water or melted paraffin. In this way the escape of mercurial vapour is avoided.

A modification of this process has recently (1868) been made by Hofmann. He employs a graduated tube of a metre in length, which is filled with mercury and inverted over a mercurial trough. A known quantity of the substance enclosed in a very small stoppered bottle is passed up into the tube, the upper part of which vessel is surrounded by a wide glass tube, through which a current of the vapour of a volatile liquid, such as alcohol, water, or aniline is passed. The volume of the vapour thus produced is read off in the ordinary way. This method has the advantage of causing the volatilisation to take place at a lower temperature than would otherwise be necessary in consequence of the diminished pressure produced by the column of mercury.

In the process of Dumas for the determination of vapour

densities, an unknown quantity of the volatile body is introduced into a weighed flask of known capacity, the neck of which is drawn out to a fine point. The flask is plunged into a vessel containing a hot liquid, and when vapours cease to issue the point is sealed with a blow-pipe flame. After cooling, the flask is weighed, whereby the quantity of substance in the gaseous condition at the moment of closing the vessel is determined. This method does not give such accurate results as that of Gay-Lussac unless the substance is absolutely pure.

Deville and Troost, by replacing the glass flask by one of porcelain, which was heated in the vapour of mercury, sulphur, cadmium, or zinc, have succeeded in determining the specific gravities of the vapours of several substances of high boiling points, and have thus obtained results of great value.

In 1873, Dewar and Dittmar, by the use of an iron bottle determined approximately the vapour-density of potassium.

Analysis of Gases.

The analysis of gases has recently attracted considerable attention, and has been brought to a condition of great exactness. The object of the first gas analysts was to determine the salubrity of the air, which was thought to depend on the varying proportions of the constituent gases in different localities. The process was hence called *eudiometry*, or measurement of the purity of air. This was first attempted by Dr. Hales, and the processes are described in his book on Vegetable Staticks published in 1727. Fontana in 1770, Priestley in 1774, and Cavendish a little later, employed nitrous air (nitric oxide, as it is now called) for removing the oxygen from a measured volume of air, Scheele employed a solution of hepar sulphuris, and Guyton de Morveau a piece of solid sulphide of potassium, heated in a retort containing the air. Seguin used warm phosphorus, and Berthollet phosphorus at the ordinary temperature for the same purpose. Volta first introduced the explosion

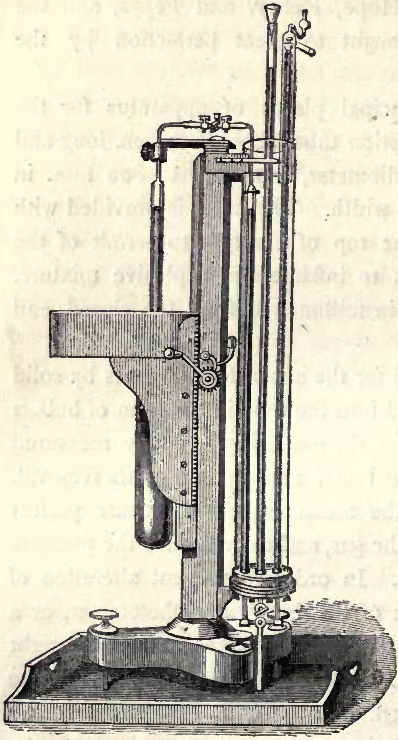
of air with hydrogen, ignition being produced by the electric spark; this method was improved by Ure, and is now found to be the most accurate one; and Döbereiner caused the union of the oxygen and hydrogen by means of spongy platinum. These processes refer entirely to the estimation of oxygen; the analyses of other gases were made by Hope, Henry, and Pepys, and the whole subject has been brought to great perfection by the researches of Bunsen.

Bunsen employs two principal pieces of apparatus for the analysis of gases—the absorption tube, about 250 mm. long and 20 in diameter, and the eudiometer, from 500 to 800 mm. in length and of about the same width. The latter is provided with platinum wires sealed into the top of the tube to permit of the passage of an electric spark to inflame the explosive mixture. These tubes are graduated in millimetres from the closed end downwards.

The short tube is employed for the absorption of gases by solid re-agents, which are introduced into the tube in the form of bullets on the ends of platinum wires, the gas being carefully measured before the introduction of the bullet and again after its removal. Great care is necessary in the measurement, to ensure perfect uniformity of temperature of the gas, and to determine the pressure under which it is measured. In order to prevent alteration of temperature by the approach of the body, a cathetometer, or a telescope sliding on a vertical rod, is used for reading the height of the mercury in the tube. The explosions are made in the eudiometer by passing a spark from a small Leyden jar or an induction coil between the platinum wires.

A considerable time must elapse between any manipulation of the tubes and the reading of the volumes of the gases; the absorption by means of solid re-agents is also very slow. To hasten the process Regnault and Reiset devised an apparatus which has since been modified by Frankland and Ward: in this the measuring tube is surrounded by a large volume of

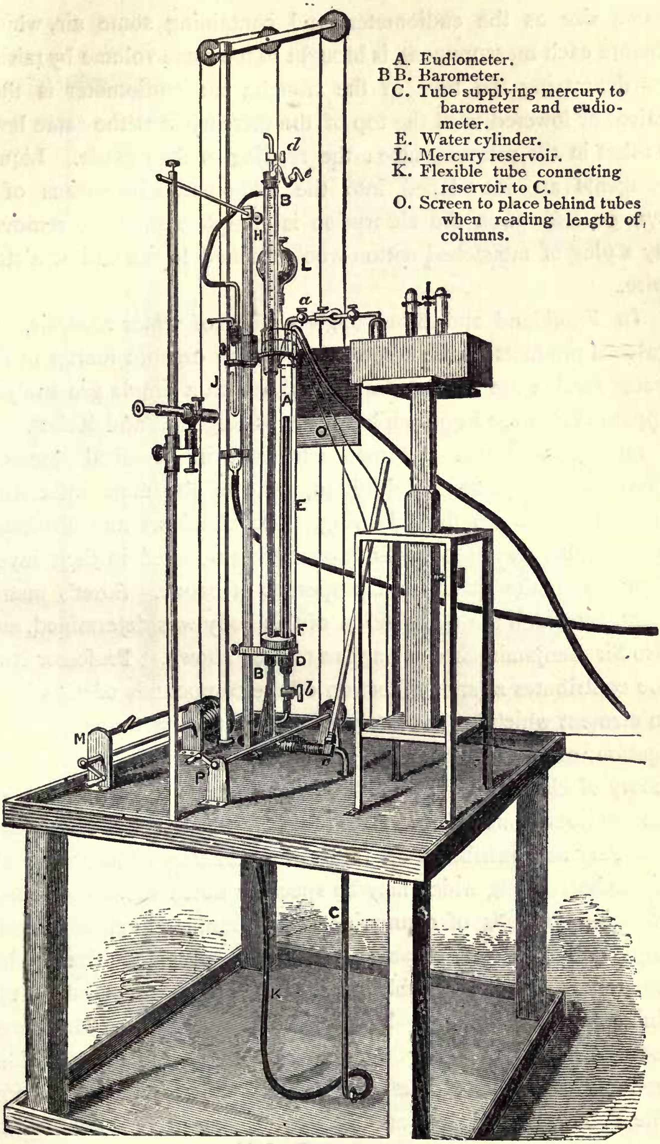
water, so that the temperature remains constant, and the absorptions are effected by means of liquid re-agents, in a laboratory tube which communicates with the top of the measuring tube by a capillary tube provided with stopcocks. In this way the absorptions are complete in about five minutes, and the measurements may be made as soon as the gas has been brought to the proper volume in the measuring tube. The latter is provided with wires, so that the explosions are made in a eudiometer surrounded by water, and no time is lost between the explosion and the measurement. Since, in Frankland and Ward's apparatus, a barometer is in connection with the eudiometer, the measurements are independent of variations of atmospheric pressure, which enormously simplifies the calculation of results. A modification of the apparatus of Frankland and Ward has been described by Mc Leod.



Apparatus of Frankland and Ward.*

More recently, Russell has described an apparatus in which ordinary eudiometers are employed surrounded by a cylinder of water. The corrections for changes of temperature and pressure are entirely obviated by the employment of a tube of about the

* This and the two following Figures are taken from "Sutton's Volumetric Analysis."

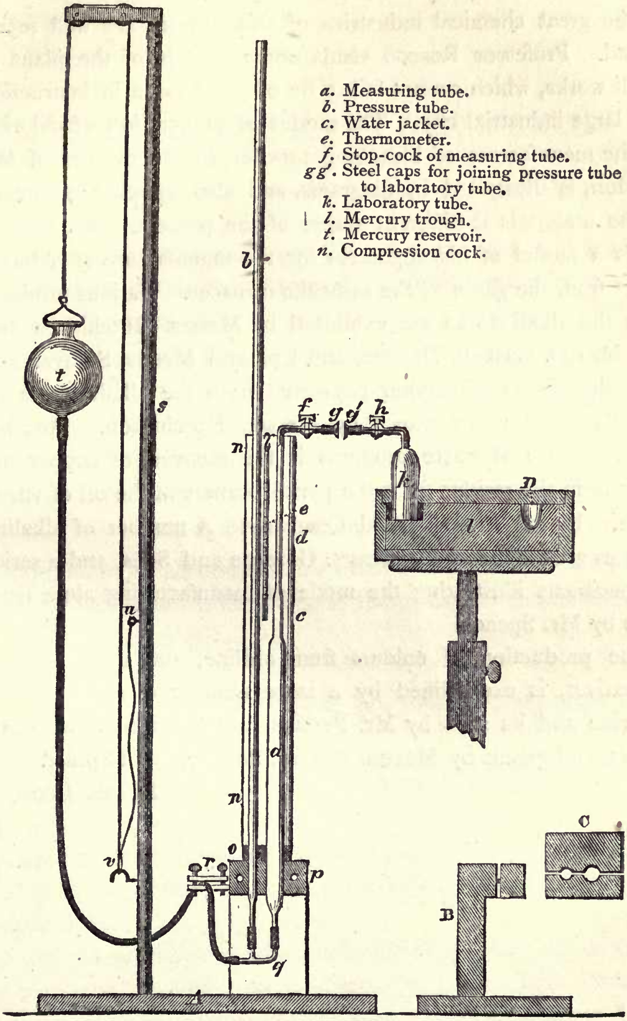


Mc Leod's Apparatus.

same size as the eudiometer, and containing some air, which, before each measurement, is brought to the same volume by raising or depressing the tube in the trough; the eudiometer is then raised or lowered until the top of the mercury is at the same level as that in the pressure tube: the reading is then made. Liquid re-agents are introduced into the eudiometer by means of a syringe, and when the absorption is complete they are removed by a plug of moistened cotton-wool attached to the end of a steel wire.

In Frankland and Armstrong's system of water analysis, the gaseous products of the combustion of the organic matter in the water residue are measured and analyzed in a simple gas analysis apparatus, similar in principle to that of Regnault and Reiset.

Of the apparatus and materials used in chemical research, shown in the present Exhibition, some of the most interesting and important are the following. Dr. Andrews and Professor Tait exhibit a complete set of apparatus employed in their investigations on the nature and properties of ozone. Soret's instrument, by which the constitution of this body was determined, and also Sir Benjamin Brodie's apparatus, are shown. Professor Roscoe contributes a large collection of the compounds of vanadium, an element which he has lately submitted to very thorough investigation, many of his results being of considerable value in the theory of chemistry. Professor Schorlemmer's investigations on the hydrocarbons of petroleum are illustrated by specimens. Mr. Perkins contributes an interesting collection illustrating his researches, among which may be specially noted those connected with the synthesis of coumarine. Dr. Frankland exhibits a very large collection of organic compounds obtained during his researches. A considerable number of bodies prepared at the University of Edinburgh by Professor Crum-Brown, Dr. Letts, and their pupils, during their investigations on the addition-products of sulphide of methyl, hyposulphites, &c., are shown. The Fellows of the German Chemical Society have combined in



a. Measuring tube.
b. Pressure tube.
c. Water jacket.
e. Thermometer.
f. Stop-cock of measuring tube.
gg′. Steel caps for joining pressure tube to laboratory tube.
k. Laboratory tube.
l. Mercury trough.
t. Mercury reservoir.
n. Compression cock.

Frankland's small Apparatus.

sending a large number of preparations, organic and inorganic, many of which are of great interest.

The great chemical industries of this country are well represented. Professor Roscoe sends some models of the plant of alkali works, which cannot fail to be of great value in instruction in a large industrial city. The modes of preparation of chlorine for the manufacture of bleaching powder, by the process of Mr. Weldon, is illustrated by diagrams, and also by some specimens of the materials at different stages of the process. Mr. Deacon sends a model of his apparatus for the manufacture of chlorine direct from the gases of the salt-cake furnaces. Various products from the alkali works are exhibited by Messrs. Hutchinson and Co., Messrs. Gaskell, Deacon, and Co., and Messrs. Sullivan and Co. Specimens of sulphur recovered from the alkali waste by Mond's process are shown by Messrs. Hutchinson. Another important use of waste products is the recovery of copper and silver from the residue from the pyrite burners in the oil of vitriol factories by the Widnes Metal Company. A number of alkaline silicates are exhibited by Messrs. Gossage and Sons, and a series of specimens illustrating the mode of manufacturing alum from shale by Mr. Spence.

The production of colours from aniline, and other coal-tar derivatives, is exemplified by a large number of specimens of mauvine and its salts by Mr. Perkins, and of aniline reds, blues, violets, and greens by Messrs. Brooke, Simpson, and Spiller.

H. Mc Leod.

METEOROLOGICAL INSTRUMENTS.

THE instrumental observations which are recognised as indispensable at properly furnished Meteorological Stations refer to the following phenomena :—

Atmospheric Pressure.
,, Temperature.
,, Humidity.
Precipitation.
Evaporation.
Atmospheric Motion, or Wind.

In addition, other phenomena are occasionally made the subjects of instrumental observation; among these may be mentioned,—

Atmospheric Electricity.
Ozone.
Specific gravity of Sea-water, as a branch of Maritime Meteorology.

These subjects will be treated in the order in which they have been enumerated. It is hardly necessary to remark that the list in question does not exhaust the catalogue of observations which must be made in order to afford a complete record of the weather at each station.

More or less complete sets of instruments, showing the outfit of meteorological stations, are exhibited by the Central Physical Observatory of St. Petersburg, the Meteorological Office, and the Meteorological Society.

Pressure.

The instrument by which this is measured is termed a Barometer ("weight measurer"), a name said to have been introduced by Boyle. The instrument was invented by Torricelli, in 1643. In its very simplest form it consists of a tube of glass, about thirty-four inches in length, closed at one end, filled with mercury, and placed with the open end dipping into a cup containing mercury, called the "cistern." The column of mercury stands in London at a height varying from about 28 to nearly 31 inches, according to the weather, &c., above the level of the mercury in the cistern. The standard barometer at Kew Observatory is an instrument of this very elementary construction. The height of the column is measured off by applying a rule to the side of the tube, and for scientific purposes the height is read off by an instrument called a Cathetometer, which consists of a telescope kept in a horizontal position and movable along a stiff vertical bar, which is carefully graduated. The telescope is successively directed to the top and bottom of the column, and carefully adjusted by micrometer screws. The difference of the readings gives the height of the column.

For ordinary purposes there are two great classes of barometers. In this we refer only to mercurial barometers, and omit all special notice of barometers mounted in wooden frames, &c., inasmuch as such instruments are not fitted for scientific observations, as explained in the "Instructions in the use of Meteorological Instruments," p. 12.

These classes are—

A, Cistern Barometers; B, Syphon Barometers.

A. In cistern barometers there is one great difficulty to be provided against, arising from the fact that there is a definite quantity of mercury in the instrument, and that when the level of the column sinks in the tube, that of the liquid in the cistern must

rise, and *vice versâ;* and as the height of the column to be measured is that above the level of the cistern, it will be impossible to measure this correctly by a fixed scale. This difficulty does not arise in syphon barometers, as in them the mercury, when it leaves the long leg, passes into the short leg, and *vice versâ;* and the height measured is the difference in length of the columns in the two legs.

1. In ordinary barometers with closed cisterns a certain height of the column is correct by the scale; this is called the *neutral point.* The proportion between the sectional areas of the tube and cistern is calculated; and from these data it is possible to calculate what is called a "capacity correction," which is applied to the reading on the fixed scale according as the level is above or below the neutral point.

2. In Fortin's Barometers, the construction of which is usually adopted for standard barometers in this country, and several specimens of which are exhibited, the scale is fixed, and its lower end, or zero, is visible in the cistern, and is formed by an ivory point. The level of the mercury in the cistern must be raised or lowered, so as to coincide with this point, by means of a thumb-screw, which is attached to the base of the cistern. This base is made of leather or other flexible material, which is movable by the action of the screw, but yet is practically impermeable to mercury.

It is evident that this construction allows of a direct measurement of the height of the column.

3. In Marine Barometers—*i.e.* in the Kew Marine Barometer, devised by P. Adie in 1854, and recommended by the Kew Committee of the British Association to the Board of Trade in the same year—a totally new principle of construction has been introduced. The extreme length of the scale is marked on the instrument, but, instead of laying off true inches, the inches are shortened from the upper part downward in proportion to the relative size of the diameters of the tube and cistern respectively.

These barometers must always be tested in a vacuometer, so that the pressure can be artificially increased and diminished. The vacuometer contains a standard barometer, and the two instruments are then read by means of the cathetometer under various pressures, ranging from 27 inches to 31 inches, and the error at each half inch is noted. This error, of course, contains the correction for capacity as well as of graduation of the scale, &c., &c.

Marine barometers have one peculiarity in construction which is not apparent, but which renders them less immediately sensitive to sudden changes of pressure than instruments intended for land service. The motion of the ship would cause the column of mercury in an ordinary tube to oscillate up and down in such a way, that at times an accurate reading could not be taken. This motion is called "pumping," and to obviate it, a part of the tube is made of a very fine bore, so that the upper portion, which is of the full diameter, is very short, and there is less mercury exposed to the pumping action. This modification meets the purpose for which it was designed, and, as the instruments are practically found to be not too sluggish for use on land, the Kew construction is being gradually more and more commonly used for all purposes, the facility of transport and of reading, as compared with a Fortin, being very great points in its favour.

Kew barometers are exhibited by Adie.

B.—Syphon Barometers. This method of construction is much used on the Continent, especially for Standard Barometers. It was first devised by Boyle, improved by De Luc and by Gay-Lussac. It is much used for mountain barometers. The new syphon barometers used in Russia are exhibited.

These instruments must be provided with a double scale, as the surface of the mercury must be observed in each leg. The fact that these two readings are taken in the same way, which is not the case in Fortin's instrument, is the great reason of the approval of the pattern for standard barometers.

Every barometer is provided with an "attached thermometer," in order to show the temperature of the mercury at each reading. This thermometer is fitted in various ways.

The words "closed cisterns," which have been used above, need some explanation. It is found that if the cistern be made of wood, the pressure of the atmosphere will exert its action through the pores of the wood on the level of the liquid in the cistern. If the cistern be made of iron, a small hole is left, which is closed with a leathern plug permeable to the air pressure, but not so to the mercury.

Self-recording instruments. Barometers are made self-recording in various ways, either by photography, electricity, or by mechanical action. All such instruments are termed Barographs. The first method gives a continuous record, and is employed at Kew and Greenwich.

In the Kew instrument, devised mainly by Sir F. Ronalds, the record is produced by allowing light to pass over the column of a cistern barometer, in this way photographing the space of the Torricellian vacuum at the top of the tube. Ronalds' original instrument is exhibited.

In the Greenwich instrument, devised mainly by Mr. Charles Brooke, the barometer is of the syphon form, and the record is obtained by photographing the position of a float resting on the surface of the mercury in the open limb.

The second method affords an intermittent record, and has been very frequently employed. The most usual process is to cause a wire to descend at frequent intervals until it touches the surface of the mercury in the open limb of a syphon barometer, and causes a galvanic current to pass, thereby eventually producing a mark on paper registering the reading. This method was first proposed by Sir Charles Wheatstone, and has been adopted, with modifications, by Dr. Theorell of Upsala, and Professor Van Rysselberghe of Ostend. The last-named gentleman exhibits his complete meteorograph, which records on the same

form and to the same time-scale the various meteorological elements and the height of the tide.

The third method also gives intermittent records. The simplest form of it is the barograph known as Sir A. Milne's, in which the record is produced by a pin attached to a float on the surface of the mercury in the open limb of a syphon barometer. This pin is driven into paper by clock-work at regular intervals.

This principle was first employed by Alexander Cumming in 1766, and the original instrument, called a "Clock Barometer," came into Mr. Luke Howard's possession, and was used by him from the year 1815.

Aneroids and Metallic Barometers are instruments very generally used as weather-glasses, but they cannot lay claim to be considered scientific instruments of the same character as mechanical barometers. Their principle was first devised by Vidi, and is that the pressure is measured by means of a volume of air which is confined in a box or case, partially exhausted and hermetically sealed. According as the pressure of the atmosphere increases or diminishes, this enclosed air is compressed or the contrary, and the envelope alters its shape accordingly. The motion resulting from this alteration of shape can be transferred to a hand moving on a dial, or can be made to record itself mechanically.

Messrs. Goldschmid, of Zurich, exhibit several specimens of their aneroids.

The objections to the aneroid for scientific observations arise from the fact that its action depends on the accuracy and delicacy of its construction, while its interior fittings, being metallic, are liable to corrosion, &c. Moreover, its action is liable to alteration owing to rough usage, as in travelling. The errors in the indications of aneroids can only be detected by comparison with the metallic barometer, and such comparisons should therefore constantly be carried out, when occasion offers, if the aneroid is to be of any use.

TEMPERATURE.

The instruments for measuring this element are termed Thermometers. The invention of the instrument is generally ascribed to Galileo. It consists of a glass tube, with a bulb at one end containing a quantity of liquid. The liquid with which it was first filled was spirit of wine, but Halley (1695) proposed the employment of mercury for this purpose, and this suggestion has been since very generally adopted, excepting for thermometers destined to register low temperatures, for which spirit is still necessarily employed.

The best instrument for the accurate measurement of temperature is the air thermometer, which consists of a portion of air confined in a hollow globe connected with a long tube, in which the volume of the air is measured. There is much difference of opinion as to the proper method of exposing thermometers so as to show the true temperature of the air. Various forms of thermometer screens actually in use will be found in the Exhibition.

The main improvement in thermometers of late years has been the graduation of the actual stem of the instrument. It is obvious that if the graduation be on a separate slab, there can be no security that the individual scale refers to the special instrument to which it is attached.

Thermometers may be made self-registering in various ways. Six's is one of the oldest patterns, and admits of the registration of both the maximum and minimum temperatures. It is a spirit thermometer with two bulbs, of which the smaller is partly full of air. The tube is **U** shaped, and the bend of the **U** is occupied by mercury, separating the two portions of spirit. The readings are registered by iron indices, which are moved by the change of position of the mercurial plug, and the instrument is reset by the use of a magnet.

This pattern of instrument was employed by Negretti, and afterwards by Casella, at Professor W. A. Miller's suggestion, for deep

sea thermometers, the bulbs being enclosed in an outer envelope of glass, and the space between the bulbs being partially filled with a liquid (mercury in Negretti's, spirit in Miller's) in order to yield when the thermometer is exposed to severe pressure at great depths, and prevent the compression of the inner bulb, which would alter the indications.

Maximum thermometers, in this country, are usually made either on Phillips's or Negretti's plan. In the former, the index is a small portion of the mercurial column, separated from it by a minute air bubble. In the latter, it is formed by the column itself. The tube is artificially contracted just outside the bulb, so that the mercury, if once forced out by the action of heat, cannot, by its own cohesion, make its way past the contraction and re-enter the bulb.

Of minimum thermometers, the most commonly employed form is that of Rutherford, which is a spirit thermometer. The index is metallic, and is enveloped in the liquid. When this recedes it draws the index with it, but when the liquid advances it flows past the index, which therefore marks the lowest temperature reached.

Casella's minimum is a mercurial thermometer provided with a lateral chamber. When the instrument is once set, this chamber being empty, if the temperature rises the mercury passes more easily into the chamber than out along the tube; while if the temperature falls the mercury returns into the bulb of the instrument. The end of the thread of mercury in the tube, therefore, marks the lowest temperature to which the thermometer has been exposed.

Thermometers are made self-recording either by photography or electricity.

The former method may be applied in various ways. At Kew the column of mercury is broken by an air speck, and the position of this speck is photographed. At Greenwich the principle is somewhat similar to that of the Kew barograph; the unoccupied space of the thermometer tube is photographed.

Electrical thermographs must necessarily have open tubes: the arrangements for record are similar to those of the electrical barographs already described.

Solar radiation thermometers are maximum thermometers with the bulb and a part of the stem coated with lampblack. They are then enclosed in another glass envelope, which is rendered as perfect a vacuum as possible before sealing.

Negretti introduces a mercurial pressure gauge to measure the vacuum. Hicks solders platinum wires into the tube, and tests the condition of the vacuum by the electric current.

Humidity.

Humidity is measured by the Hygrometer, and this can be effected either in the direct or indirect way. Daniell's hygrometer belongs to the former class, and is exhibited by Mr. Symons. It consists of two bulbs connected by a tube; one is of black glass and contains a thermometer, the other of clear glass and enveloped by muslin. Some ether is introduced into the instrument before sealing. The mode of making an observation is to drop some ether on the muslin; this cools the coated bulb, and the ether inside the instrument is condensed in that bulb. The evaporation causes the temperature of the black bulb to fall, and the moment of deposition of dew on it from the external air is observed. The temperature at which this takes place is given by the enclosed thermometer.

Regnault's is a better form of direct hygrometer. In it the thermometer is enveloped in a silver casing, ether is introduced into the casing, and its vapour removed by an air-pump. Dew forms on the silver when the temperature falls sufficiently.

Of indirect hygrometers only two need be noticed—Saussure's, in which the moisture of the air is measured by the length of a hair, which stretches when wet, and shrinks as it dries. This motion is transferred to a hand moving on a graduated arc. The

instrument is still much used in cold climates. It is exhibited among the Russian instruments, and elsewhere.

The Psychrometer, called also Mason's, or August's, or the Dry and Wet Bulb Hygrometer, consists of two thermometers, one of which has its bulb coated with muslin and moistened with water. The theory of this instrument is explained in the "Instructions in the Use of Meteorological Instruments," p. 47.

PRECIPITATION.

Rain is measured by means of a rain-gauge, which in its simplest form consists of a funnel to catch the rain and a vessel to receive it. This vessel may be either a bottle (Howard), or a cylinder (Glaisher). It is then measured either by the use of a graduated rule to measure the depth, or by pouring the amount into a graduated glass cylinder. The various forms of rain-gauge are very numerous.

Snow is usually collected in a rain-gauge, but such a measurement is very deceptive, as owing to wind the flakes are often blown out of the gauge, while in heavy falls the gauge is filled and piled up with snow, so that the true amount cannot be well ascertained. Babinet's gauge is provided with a lamp underneath to keep the funnel hot and thaw the snow which falls. The measurement of snow, by gauging the depth of the coating on a level surface, is unsatisfactory, owing to the liability of snow to drift.

Rain-gauges are made self-recording in various ways, either by a system of tilting buckets, which make a mark whenever each bucket-full has been received and discharged, as in Crossley's gauge. In Beckley's gauge, adopted by the Meteorological Committee of the Royal Society, the bucket holds 0.2 inches of rain. It is carefully counterpoised, and as it descends, according as the rain accumulates, it moves a pencil which marks a paper. It therefore yields a continuous record.

EVAPORATION.

Instruments for the measurement of evaporation are called "atmometers," or more correctly, "atmidometers." They consist in principle of an open dish filled with water, and allowed to remain for a length of time exposed to the air. The amount of water removed by evaporation is measured either by volume (Von Lamont, Dufour, Dr. A. Mitchell), or by weight (Osnaghi [exhibited] and S. H. Miller). Most atmometers are only fitted for exposure in a screen, so as to be sheltered from rain and wind, and so can only indicate in a very modified degree the true evaporation in the open air.

Moreover, it is doubtful whether the results of experiments made with small instruments are applicable to large water surfaces.

WIND.

Wind is measured either by its pressure on a definite surface, or by its velocity.

Of pressure gauges, the best known is Osler's. In this a plate of known area is driven back against a spring, and its motion recorded on paper. In Cator's instrument (exhibited) the resistance is furnished by levers instead of springs. The principle of these arrangements was first devised by Bouguer.

A very simple form of Pressure Anemometer is Wild's (exhibited among the Russian instruments), in use in Russia, Norway, and Switzerland. It consists of a rectangular plate hung on hinges on a horizontal axis. The angle which this makes with the vertical indicates the force of the wind. The first propounder of this idea is unknown. It is evident that this instrument is not self-recording.

The idea of employing the vanes of a windmill to measure the velocity occurred to Ch. Wolff, 1743, and was afterwards adopted by Whewell.

Robinson's anemometer is practically the only velocity anemometer now in use. The principle of the instrument is, that the wind will cause a set of four hemispherical cups attached to arms in the form of a cross to rotate with one-third of its own velocity.

It is evident that this instrument may easily be made self-recording, as there is abundance of power available to move a pencil. Beckley has added a windmill-vane arrangement to indicate the direction, and the instrument so altered has been adopted by the Meteorological Committee. Self-recording anemometers are called Anemographs.

Professor von Dettingen of Dorpat exhibits his new "Self-recording Wind-Components Integrator."

Atmospheric Electricity.

This phenomenon is not observed at all stations. The nature of the electricity present in the atmosphere can be determined by a simple instrument such as the Gold Leaf, Bennett's or Bohnenberger's electroscopes. In order to collect the electricity at a distance from the earth's surface, a metallic arrow with a conducting string attached may be shot into the air, the end of the string resting on the plate of the electroscope; Volta proposed to collect the electricity by means of smoke; Sir W. Thomson, by means of water dropping from a fine pipe.

The principle of Thomson's two electrometers, viz.,

1. The Quadrant or Modified Divided-Ring Electrometer, for observatory use.
2. The Portable Electrometer—

will be found in the "Instructions in the Use of Meteorological Instruments," p. 60. Thomson's electrometer may be described as a combination of Coulomb's Torsion Balance and a Leyden Jar.

Peltier's electrometer is described by Sir Charles Wheatstone,

in the Report of the British Association, 1849, p. 11. It measures the electricity by the displacement of a delicately suspended magnetic needle out of the magnetic meridian.

Ozone.

The great difficulty in the measurement of this element is to secure a chemical reaction which shall be an infallible indication of the presence of ozone in the air, as the action of light, &c., or of oxidizing agencies independent of ozone, has been generally found to disturb the correctness of the indications of the test papers.

Schönbein proposed paper soaked in iodide of starch.

Specific Gravity of Water.

Instruments for measuring this element are termed Hydrometers. Those used at sea consist of a small glass bulb loaded with shot or mercury. Above this a cylindrical bulb is blown, and the upper portion of the tube, which is retained as a slender stem, is graduated. The depth to which the instrument sinks in water is shown by the scale, and the specific gravity is read off, at the level of the water.

Miscellaneous Instruments.

Among these may be specially mentioned the automatic light-registering apparatus of Professor Roscoe, which is exhibited, as well as a smaller form of the instrument by Captain Abney. The principle of the method consists in the fact that the depth of colour produced on chloride of silver is proportional to the intensity of the light multiplied by the duration of the time of exposure.

In addition to actual instruments, several exhibitors have furnished charts and diagrams showing the results at which they have arrived on the progress of their investigations. The most

noteworthy of these are the Scottish Meteorological Society, who supply charts of the mean temperature, and of the rainfall, of the British Isles, as well as a most important series illustrating the investigations of Dr. A. Mitchell and Mr. A. Buchan into the connection between weather and sanitary conditions.

R. H. SCOTT.

GEOGRAPHICAL INSTRUMENTS AND MAPS.

I.—Instruments used for Geographical Purposes.

The dawn of modern geography broke upon the world when Prince Henry of Portugal began to send forth his expeditions along the coast of Africa; and it was the needs of the daring seamen of that age which caused the demand for geographical apparatus to be met. The first geographical (as distinguished from astronomical) instruments were those for ascertaining the position and course of a ship; they were used by the discoverers of the fifteenth and sixteenth centuries, and the results consisted in the delineation of new coast-lines, and of their most prominent features.

The compass and the rough sea card were the only appliances until the learned Nuremburger, Martin Behaim, invented the application of the astrolabe to purposes of navigation, which enabled mariners to ascertain their latitude. This was in the year 1480. The astrolabe was used by Vasco da Gama on his first voyage round the Cape of Good Hope; but the movement of a ship rendered accuracy impossible, and the liability to error was increased by the necessity for three observers. One held the astrolabe by a ring passed over his thumb, the second measured the altitude, and the third read off. Some years afterwards the cross-staff was invented to take the altitude of the sun or of a

star; and in many of the early voyages of discovery both astrolabe and cross-staff were in use. But the cross-staff was generally preferred by our English mariners because the graduation was larger and more easily read off. It was a very simple instrument, consisting of a graduated pole, with cross pieces, called transversaries (of which there were four, used according to the altitude), also graduated, which were fitted to work on it. The bearing of the sun was taken by compass, to ascertain when it was near the meridian, then the end of the long staff was placed close to the observer's eye, and the transversary moved until one end exactly touched the horizon and the other the sun's centre. This was continued until the sun dipped, when the meridian altitude was obtained. The back-staff was an improvement on the cross-staff, invented by the great arctic navigator, John Davis. It was fitted with a reflector, and it was thus the first rough idea of the principle of the quadrant and sextant. The astrolabe was a metal circle graduated round the edge, with a limb, called the *alhidada*, fixed to a pin in the centre, and working round the graduated circle. It had two sights fitted upon it, one at each end. The instrument was suspended by a ring, so as to hang vertically on one hand, while with the other the *alhidada* was worked up and down until the sun could be seen through both the sights. It then gave the zenith distance. The cross-staff was used for low altitudes because both ends of the transversary could easily be seen at the same time; and the astrolabe for high altitudes. With the invention of these instruments came instructions for their use, and for working out observations. In this country, the first of these was "The old Rutter of the Sea," printed in 1490. Then followed the "Seaman's Secrets," by John Davis, and "A Regiment of the Sea, containing very necessary matters, with a perfect sea carde," by Thomas Hood, published in 1596. These ancient manuals contained definitions, a treatise on the use of the sea card, or chart and compass, tables of declination, instructions for observing with cross-staff and

astrolabe, the rule for applying declination, rules for dead reckoning, and for longitude. Latitude was obtained by observation, but longitude had usually to be reckoned on the chart from the meridian of the Canary Islands, which in those days was used by all civilised countries. The difference of time between the eclipses of the moon at the place of the observer, and the place for which it was calculated in the *ephemerides* of that day was another method in use, for finding the difference of longitude. Mariners were also provided with tables, giving the number of miles in a degree of longitude, for every degree of latitude.

By means of these rough instruments and calculations our Elizabethan navigators, and their contemporaries in Spain, Portugal, France, and Holland succeeded in delineating the vast regions that were discovered, and thus increased the sum of human knowledge, while men's minds were enlarged, and the wealth and prosperity of nations were increased.

The improvement of scientific apparatus naturally went hand in hand with the progress of discovery. The great desideratum was the means of finding the longitude; and it was the creation of a commission for the discovery of longitude in 1713, which, so far as this country is concerned, gave the greatest stimulus to inventions connected with geographical research. To the Board of Longitude is due the conception of the Nautical Almanac, and the establishment of a surveying branch of the naval service. The Nautical Almanac first appeared in 1767, under the auspices of Dr. Maskelyne, the Astronomer Royal, who, by furnishing tables of lunar distances, supplied another means of finding the longitude. The invention of the quadrant, for use at sea, in 1731, by Hadley, which entirely superseded the astrolabe and cross-staff, in taking the altitude of heavenly bodies, was a still greater improvement; and it was soon followed by better instruments on the same principle—the sextants of Dollond and Troughton.

The work of travellers on shore also became more accurate

in proportion as instruments and maps were improved. Early explorers by land were content with itineraries and maps which only indicated distances, as the Pentinger tables. The observation of bearings by compass introduced an important improvement; and after the invention of Hadley's quadrant, these rough route surveys began to be checked and verified by astronomical observations. Bruce, when he went to Abyssinia, took with him a quadrant which it required three men to carry, and he made excellent use of it; and Major Rennell, in his survey of Bengal between 1763 and 1782, measured his distances by chain, and observed both for latitude and longitude at fixed stations.

The modern traveller needs a good watch, a sextant, an artificial horizon, an azimuth compass, a nautical almanac, and tables. He must also be supplied with aneroids and boiling-point thermometers, to enable him to construct a section of the country he traverses, and delineate its principal physical features. The maps constructed from materials so obtained are sufficient for wild and little-known regions, and for countries a knowledge of which is only needed for political or commercial purposes. In this category by far the greater part of the earth may be placed. Such maps are based on as many positions as possible, which are fixed by astronomical observations, while the intermediate country is delineated by careful traverses and route surveys, and by plane tabling. But the charts of coasts, upon which the safety of ships depends, cannot be prepared with too close an attention to accuracy. Running surveys are not now sufficient for frequented coasts, and important marine surveys have long been executed on a trigonometrical basis.

The scientific apparatus required for geographical work differs according to the amount of accuracy required; and when maps are called for, not merely for political, military, or commercial, but also for administrative uses, the very highest degree of accuracy is desirable, and has been attained. It is, consequently, in the execution of cadastrai surveys that the greatest

triumphs of the geodesist have been secured; and that a degree of precision in measurement has been reached which to the uninitiated really sounds almost incredible.

Surveys are the basis of statistics and of administration, and consequently rigorous accuracy is necessary. Hence their operations are most valuable aids to pure science, and are especially identified with investigations connected with the shape of the earth, and with measurements of arcs of the meridian. Surveys on a trigonometrical basis have now been commenced in all, and completed in most of the countries of Europe (except Turkey); and the United States Coast Survey has also been converted into a regular trigonometrical survey on rigorous principles.

In Great Britain the Ordnance Survey was begun in April, 1784, when General Roy measured a base line on Hounslow Heath. The triangulation of the British Isles was commenced in 1784, and completed in 1852, and about 250 points have thus been determined with the most extreme accuracy. The two base lines, on Salisbury Plain and on the borders of Lough Foyle, were measured by the 10-feet compensation bars invented by General Colby. The Lough Foyle base was measured in 1827, that on Salisbury Plain in 1849. An idea of the minute accuracy of these measurements may be formed from the fact that, when a portion of the Lough Foyle base was re-measured, the difference between the old and new measurements was only one-third of the finest dot that could be made with the point of a needle. The accuracy of the base line measurements was put to a still more rigid test. The bases on Lough Foyle and Salisbury Plain are 360 miles apart, and taking the measured length of the former to start with, the length of the Salisbury Plain base was computed through the intervening network of triangles, and compared with its measured length. The difference was found to be about 5 inches. The instruments used in the triangulation were two 3-feet theodolites made by Ramsden, an 18-inch theodolite by Ramsden, and a 2-feet theodolite by Troughton and Simms.

The sides of the triangles average 35 miles in length, but some are over 100, and one 111 miles long. The two distant stations of the side of a triangle were connected by the use of a *heliostat*, or revolving plane mirror for reflecting the sunbeams from the point to be observed towards the far-off station. But, in this climate, sometimes weeks elapsed before the gleam of light was seen. Similar accuracy was obtained in measuring vertical angles, the difference between the height of one of the Scotch mountains so measured, and as ascertained by spirit level, being one inch and a half.

The exact measurement of an arc of the meridian of 10°, from the Shetlands to the Isle of Wight, was included in the operations of the survey. By combining this measurement with those of arcs of the meridian measured near Quito on the equator, in India, France, Hanover, Denmark, Prussia, Russia, and Sweden, Colonel Clarke found the figure of the earth to be a spheroid with an equatorial semi-axis of 20,926,350 feet, a polar semi-axis of 20,853,429 feet, ellipticity $\frac{1}{29967}$. By 1860 the trigonometrical surveys on the Continent were also approaching completion, and it was determined, by connecting them, to measure an arc of the 52nd parallel of latitude, from Valentia on the west coast of Ireland, to Orsk on the river Ural, a distance of more than one-fifth the circuit of the globe. The English triangulation was successfully connected with those of France and Belgium in January, 1862.

As a preliminary step to the measurement of this great arc of parallel, the standards of the world were sent to Southampton, for comparison with those of England, in 1865. Those of India, Russia, Belgium, Prussia, Austria, Spain, Italy, and the United States were compared by Colonel Clarke at Southampton. These two great works, namely, the comparison of the standards of length, and the connection of the various national triangulations for measuring an arc of parallel, are the crowning achievements of geodesy. The latter operation is still in progress.

For the detail surveys a series of minor triangles is observed by 7-inch theodolites, resting on the stations of the primary triangles, and with sides about a mile in length, and the boundaries and topographical details are then filled in by the chain surveyors. To the survey is added a most complete and comprehensive system of levelling, lines being run along nearly all the roads, and bench marks cut at intervals of about a quarter of a mile.

It is remarkable that the commencement of the trigonometrical survey of India should only have been preceded by that of Great Britain, by eighteen years. The Indian Survey was begun at Madras by Major Lambton in 1802, the bases being measured by steel chains, and the angles taken by a 3-foot theodolite of Cary. Lambton worked for twenty years, and his mantle fell upon Colonel Everest, who, in 1830, re-commenced the survey with Colby's compensation bars, and more perfect instruments. In 1841 he brought to a close the series of triangles for the great arc of India, which extends from Cape Comorin to the Himálaya. The triangulation of India was continued under Sir Andrew Waugh and Colonel Walker, and is now approaching completion; the accuracy being equal to that attained in the survey of Great Britain. In 1867 the new base line was measured at Bangalore, and the difference between the measurement and the length as completed through a network of triangles, from the Vizagapatam base was a quarter of an inch. A new set of instruments,* constructed under the superintendence of Colonel Strange, has recently been forwarded to India. It consists of a magnificent theodolite with a 3-foot horizontal circle, two zenith sectors, two 5-foot transit instruments, two smaller ones, two 12-inch vertical circles, two galvanic chronographs for registering transit observations, and three astronomical clocks.

In India, as in Great Britain, the stations of the primary triangles form the points of departure for the secondary tri-

* Photographs of these instruments are in the Exhibition.

angulation, by means of which the boundaries are fixed, and topographical details are filled in by the topographical and revenue surveyors, under the Surveyor-General; the former working in the wilder and more thinly-peopled tracts, and in the native states, and the latter in populous districts where, for administrative purposes, minute accuracy is essential.

As in Great Britain and India, so in all the Christian nations of Europe, in the United States, and in some of our colonies, trigonometrical cadastral surveys have been undertaken with a view to the supply of rigorously accurate maps for statistical and for numerous administrative uses.

Thus the scientific apparatus required for the several classes of geographical and geodetic operations, varies in proportion to the degree of accuracy required. For the ordinary work of navigation, and for the execution of running surveys of newly-discovered coast lines the sextant, chronometer, sounding lead and line, and compass suffice. But for the preparation of charts of much frequented seas and channels the marine surveys must be executed on rigorous trigonometrical principles. In the same way on shore, the explorer of an unknown country need only make a careful traverse, with a section, and points fixed at intervals by astronomical observations with the sextant and artificial horizon. For political boundaries of semi-barbarous countries, military reconnaissances, and more frequented routes, somewhat greater accuracy is needed. In Persia, Major St. John carefully measured the distances with a perambulator, ascertained the longitude by the use of the electric telegraph, besides taking the usual observations with the sextant. But when very accurate maps are needed, the geodetic instruments are used which are capable of giving exact results, and only errors of a few inches are admissible in as many hundreds of miles.

CLEMENTS R. MARKHAM.

II.—Geographical Maps.

Geography is the science by means of which the surface of the earth is delineated and described, boundaries are defined, areas are exactly measured, and the relative positions of places are determined. Political geography defines the present divisions of the earth under its various governments. Historical or comparative geography records the successive changes which have taken place in past times. Physical geography turns from the political aspects to the natural, and explains the different features of the earth's surface, and the conditions that operate upon it. The history of the progressive discoveries that have been made in the delineation and exact measurement of the earth, of the labours of the discoverers, and of the various uses to which their work has been adapted, completes the knowledge by means of which this science may be understood and studied.

The history of geography is a subject which naturally divides itself into three parts: first, the tools, secondly, the labourers, and thirdly, the results:—first, the scientific apparatus by means of which the measurements and delineations are effected; second, the work of explorers and geodesists in the field; and third, the practical utility to mankind of geographical research and exact surveys.

The three branches of the subject cannot fitly be considered separately, because they are, in every stage, dependent upon and closely connected with each other. The explorer and the geographical student, from age to age, as their science advances, on the one hand discover wants which must be met by the improvement of old or the invention of new appliances, and on the other fresh demands are made upon them as the results of their labours become more important to science, and more useful in all the administrative details of life.

The construction of charts and maps is a branch of geographical work which received improvements in proportion as the observing instruments were made more perfect. While a chart was a necessary part of the scientific apparatus for an explorer, the chief result of his work was to extend and improve it; and as the more exact instruments continued to fix positions with greater accuracy, so the delineation of coast-lines became more correct.

Thus the history of geography becomes very instructive. While, on the one hand, the inspection of a series of sextants, and of compasses of different dates, will exhibit the inventive talent which was brought into play as ever-increasing demands were made upon it, and the new adaptations which were gradually developed; on the other, the examination of a chronological series of charts will show the effect which improved scientific instruments had upon their construction, and also the gradual process by which succeeding generations of cartographers have developed new ideas, and more graphic methods of delineating the features to be exhibited.

The character of maps varies according to the uses that are required from them; from the rough sketch of the pioneer of discovery in a previously unknown country to the elaborate map prepared as an aid to the calculation of the valuation of land for taxation, or as the means for settling questions of property or jurisdiction.

The maps of the Ordnance Survey of the United Kingdom, and of the Revenue Surveys of India are of the latter class. For the United Kingdom there is a topographical map of the whole country on a scale of one inch to a mile ($\frac{1}{63360}$), and there will be county plans on a scale of six inches ($\frac{1}{10560}$), and parish plans on a scale of twenty-five inches ($\frac{1}{2500}$) to a mile, the latter only for cultivated districts in England and Scotland, not already finished on the six-inch scale. In 1871 the detailed plan of London was completed on the five-feet scale, drawn on 326 sheets.

The one-inch quarter sheets and the six-inch sheets are published and sold at prices which place them within reach of every one to whom they are likely to be of use; and no one in the United Kingdom need be without a beautiful and accurate topographical map of his neighbourhood; or an exact plan of his property or holding. Equally good maps are now either completed, or in rapid progress, for all European countries, and are the most serviceable instruments in the hands of the statesman, the administrator, and the statistician; as well as the most indispensable guides for the student of history, the engineer, the lawyer, and the farmer. The uses indeed of maps based on accurate surveys are too various for concise enumeration; for there is no public department, and few private enterprises or investigations which do not require the assistance of maps.

In British India the utilisation of the surveys by the publication of maps on adequate scales has of late years made rapid progress under the able superintendence of Colonel Thuillier.

The Indian Atlas was commenced in 1827, and designed to occupy 177 sheets, on a scale of four miles to an inch, and it is now approaching completion; while larger-scale topographical and revenue maps, and plans of towns and stations, promptly utilise the surveying work that is done in the field each year. In the colonies such work is not so far advanced; but trigonometrical surveys have either been organized or are about to be commenced; while the United States surveys are in full operation. In other countries, which have been surveyed trigonometrically, the work in the field has also been utilised, and made available for the public, with more or less promptitude. Thus in France a cheap edition of the topographical map is in course of publication; in Belgium the Government maps are on double the scale of those in France, in consequence of the minute subdivision of holdings; in Switzerland the completed map, in twenty-five sheets, brought out under the auspices of General Dufour, appeared in 1866; and in all other European

countries, except Turkey, the results of the trigonometrical surveys have either been published or are in progress.

Eventually such maps will explain and illustrate the physical aspect of the whole globe. But at present they are necessarily confined to those nations which are in the front rank of civilisation. Countries which are not so advanced are still obliged to be content with such maps as sufficed for all the world fifty years ago, before the results of trigonometrical surveys were available. These secondary maps are well adapted for the requirements of the countries which use them, being based on positions fixed by astronomical observations, on cross bearings, and often on chained distances.

In the category of second class maps, that of the Empire of China takes the first place, both for antiquity and probably for general accuracy. The Chinese Survey was commenced by the Jesuit missionaries, under the auspices of the Emperor Kang-hi in 1708, and the maps were completed in 1718. The records preserved in each city had been examined, topographical information had been diligently collected, and the rough triangulation had been checked by meridian altitudes of the sun and the pole star, and by re-measurements. Our knowledge of by far the larger number of the provinces of the Chinese empire is still dependent on these maps. In an inferior position to China, as regards maps, are such countries as Persia and Turkey, which depend on careful compilations from the observations of travellers. There are, however, maps of some portions based on regular surveys, such as Mesopotamia and Syria.

In South America and Mexico, too, our dependence is still on compiled maps from the observations of travellers, or else upon partial surveys which have not been executed on rigorously accurate principles; yet the first arc of the meridian was measured in South America, and the bases then traced in the province of Quito, the marks for which were restored by Don Vicente Rocafuerte, the enlightened President of Ecuador, would even now

serve as initial points for future survey. In Venezuela we have the map of Codazzi, in Colombia that of Acosta, in Ecuador the very incorrect production of Villavicencio. In Brazil better work has been executed, and there are some fine surveys of the San Francisco and other rivers. An atlas of Peru was brought out by Paz Soldan; but it will probably be eventually superseded by the magnificent topographical work of Don Antonio Raimondi, published at the expense of the Peruvian Government. The topographical maps of Chile were brought out by Pissis, and a good deal of useful surveying work has since been done by Chilian officers. In this way the countries in the second rank of civilisation are adequately supplied with maps, until the time comes when their increasing requirements necessitate the execution of first-class trigonometrical surveys.

The third class of maps includes the work of explorers of unknown or little known regions, and of geographers who delineate the features of such regions by compilation and by an intelligent collation of the work of travellers. In this category are the maps of a great part of Central Asia, of Afghanistan, and Arabia; of the interior of tropical Africa; of the Montañas of Bolivia, Peru, Quito, and Colombia; and of the Arctic and Antarctic regions.

There are thus three grand divisions in the character and uses of maps. There are, first, those which aim at minute accuracy, and which are intended as documents for administrative and judicial purposes, and in pursuing exact statistical investigations. Secondly, there are maps which are based on less accurate surveys, of countries less populous or less advanced in civilisation. These are useful for military, political, and geographical purposes, but are not to be relied upon to the same extent or in the same way as is the case with those based on trigonometrical surveys. Thirdly there are the roughly-compiled maps of little known regions, which are constantly in course of improvement. The regions which are only represented by such temporary maps are of vast extent, and it is the task of the Royal Geographical

Society to reduce their area. This great aim has been steadily persevered in for forty-six years, and the interval has seen a very extensive amount of work done. But a still greater extent remains untouched round the north and south Poles, in Asia, Africa, South America, and in the eastern islands. For many years to come the Society must continue its efforts and offer its rewards *ob terras reclusas*.

The instruction to be derived from the study of a large collection of maps, especially of a complete series representing the same region at certain intervals of time, is varied in its character, and extends to several branches of knowledge. To the historian such study is indispensable for the due appreciation and efficient handling of his subject. The historian who has not got the geographical instinct is without one of the most necessary qualifications for his task; and there is no more useful aid to the historical student than maps showing the territorial divisions of a region at various periods; such, for instance, as those given by Mr. Freeman in his History of the Norman Conquest.

The study of a series of maps of the same region may often throw light on the physical changes that have taken place, and thus convey knowledge respecting the tendencies of changes in the courses of rivers or the condition of harbours, which may be of the utmost value to administrators, and especially to engineers. It is thus that we learn the marvellous changes that have taken place in the valley of the Indus. Multan, as we know through these comparisons, was once on an island in the Raví. It is now thirty miles from that river. The classic Saraswati once watered a now arid desert, and the history of the change is taught to us by comparative geography. The gradual changes in the deltas of the Ganges and Brahmaputra are of the utmost importance, and their character is revealed to us by a comparison of Major Rennell's first maps of Bengal, and of the still earlier Dutch maps, with the results of the latest surveys. The same causes are still at work, and by learning their tendency in former

times most important knowledge is acquired of what will ensue hereafter, and of the character of the means that are necessary to avert mischievous action, or to guide and control natural forces.

The examination of a series of maps of one region is most fascinating to a geographical inquirer; for there is no other means by which he will obtain so clear and definite a knowledge of the progress of discovery, and of the adaptation of scientific apparatus to geographical purposes. In the early dawn of modern times, when the traveller by land used no scientific instruments, and the mariner had only his compass and cross-staff, the resulting maps were very rough, and the attempts to delineate mountains and rivers were rude and altogether conventional. At the same time these old maps were frequently marvels of accuracy, considering the inadequate means, and were beautifully drawn. The improvements in the art of map-making steadily advanced with the parallel improvements in scientific instruments; and as the cartographer was supplied with more accurate and fuller materials, so he delineated them with greater skill and less conventionality. The study of a series of maps, while thus illustrating the progress of the art of cartography, also conveys to the mind of the inquirer a lucid and exact knowledge of the progress of discovery; and it is thus that real benefit is to be derived from an intelligent examination of a carefully selected collection of maps, side by side with a similar collection of scientific instruments for geographical purposes.

CLEMENTS R. MARKHAM.

III.—Collection of Arctic Maps.

List of Maps exhibited.

1. Facsimile of the ancient chart of the Zeni. (R.G.S.)*
2. The map of Hondius, from Pontanus. (H.S.)
3. Petermann's map, showing the track of Barents. (R.G.S.)
4. Gerrit de Veer's map of the voyage of Barents. (R.G.S.)
5. Map of Spitzbergen from Purchas. (G.M.)
6. Hudson's map of 1612. (H.S.)
7. Van Keulen's chart of Spitzbergen. (G.M.)
8. Dutch chart of Davis Strait after 1721: translated into English. (A.)
9. Phipps's MS. chart of North Spitzbergen. (A.)
10. Circumpolar chart of 1818. (R.G.S.)
11. Chart of Baffin's Bay, by John Ross, 1818. (A.)
12. Buchan's voyage to Spitzbergen, with tracks. MS. by Beechey. (A.)
13. Chart of Parry's discoveries. First voyage. MS. by Liddon. (A.)
14. Parry's discoveries. First voyage. MS. by Bushnan. (A.)
15. Parry's discoveries. Second voyage. MS. by Bushnan. (A.)
16. North of Spitzbergen and Parry's track in 1827. MS. by Foster. (A.)
17. Graah's chart of Julianshaab, Greenland. (R.G.S.) Danish map of Greenland, with Eskimo names. (R.G.S.) Moller's chart of Baal's river and the Godthaab district. (R.G.S.)
18. Circumpolar chart of 1835. (A.)
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20. Simpson's chart, from Point Barrow to Return Reef. (R.G.S.)
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23. Parry Islands and Arctic America, 1850. (A.)
24. Track of H.M.S. *Assistance* to the Cary Islands, 1851. (A.)
25. Sutherland's circumpolar physical map, 1851. (R.G.S.)
26. Charts by Arrowsmith of the coast of Arctic America, showing Dr. Rae's journeys. (S.)
27. Herald Island, MS. and views. (R.G.S.)
28. Chart of Baffin's Bay, with Captain Inglefield's corrections. (A.)

* References.

(R.G.S.) From the collection of the Royal Geographical Society.
(A.) From the Admiralty.
(H.S.) From the Hakluyt Society's volumes.
(G.M.) From the *Geographical Magazine.*
(S.) From Mr. Stanford.

29. Discoveries of M'Clure (4 sheets MS.) (A.)
30. Arrowsmith's chart showing the discoveries of M'Clintock in 1859. (R.G.S.)
31. M'Clintock's discoveries. MS. by Allen Young. (A.)
32. Circumpolar chart of 1859. (R.G.S.)
33. Admiralty chart of Kane's discoveries up Smith's Sound. (R.G.S.)
34. Kane's original MS. chart of his discoveries. (R.G.S.)
35. Petermann's map of Wrangell Land, 1869. (R.G.S.)
36. Captain Long's chart and sketch of Wrangell Land, 1867. (R.G.S.)
37. Swedish chart of Spitzbergen.
38. Petermann's map of Nordenskiold's voyage to Spitzbergen in 1868. (R.G.S.)
39. Petermann's map of the north end of Novaya Zemlya, 1872. (R.G.S.) Petermann's maps of Novaya Zemlya, Waigat Isles, Matotchin Shar, &c. (R.G.S.)
40. Track of Captain Koldewey's voyage in 1868, by Petermann. (R.G.S.)
41. Discoveries of the German expedition on the east coast of Greenland. (R.G.S.)
42. Franz Joseph Land. Discoveries of the Austrian expedition. (R.G.S.)
43. Map showing the "Hypothesis Petermann," and making Smith's Sound a *cul de sac*. (R.G.S.)
44. Polar discoveries of Hall in the *Polaris*, American chart. (R.G.S.)
45. Map showing the drift of the boat of the *Polaris* down Baffin's Bay, by Petermann. (R.G.S.)
46. Track of the *Arctic* in 1873, by Commander A. H. Markham, R.N. (G.M.)
47. Circumpolar chart by Stanford, 1875. (S.)
48. Track of the *Alert* across the Atlantic. (A.)
49. Disco Island. (G.M.)
50. Track of the *Alert* from Upernivik to the Cary Isles. (G.M.)
51. New chart of Baffin's Bay. (A.)
52. New chart of Smith's Sound. (A.)
53. New half circumpolar chart. (A.)
54. Chart showing winter quarters of all expeditions. (A.)
55. Projection for the use of the present Arctic Expedition. (A.)

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1. THE study of a selected series of maps and charts, illustrating the gradual progress of discovery in the Arctic Regions, is the best means of acquiring a clear and definite knowledge of the work done by the long roll of expeditions, ending in that which is now wintering on the verge of the still vast unknown area.

1. Facsimile of the ancient chart of the Zeni. (R.G.S.)

2. The original ancestor of all the Arctic maps is the famous chart of the Zeni, to illustrate their voyages in the fourteenth century, the history of which has been so admirably elucidated by Mr. Major. On it we have the Orkneys, Shetlands, Faröes, and Iceland, with their relative positions fairly correct; Engroenland so delineated as to cause bewilderment and confusion to future geographers; and Frisland, with other strange lands in the west.

3. The Dutch were the fathers of modern geography; but much of the material for their earlier maps of the far north was derived from the chart of the Zeni. However, the charts of the north polar regions by Hondius, given in Purchas and Pontanus, are a good point of departure whence to start on our surveying voyage among the gradually developing charts which have, year by year, and century by century, improved and extended the knowledge of our earth. If, as we proceed, we consider the objects which led to new discoveries, it will be seen that Arctic voyages have not only produced valuable results to science, but that they have also increased the wealth and prosperity of the nations which have taken part in them.

2. The map of Hondius, from Pontanus. (H.S.)

3. Petermann's map, showing the track of Barents. (R.G.S.)

4. Gerrit de Veer's map of the voyage of Barents. (R.G.S.)

4. Hondius, then, who partly copies from the still more ancient map of the Zeni, shows us what was known in the closing years of Queen Elizabeth's reign. There are the coasts of Lapland to Archangel, the west side of Novaya Zemlya, the west and part of the north shore of Spitzbergen, discovered by the gallant Barents, in his "Admiranda Navigatio" of 1596, and an indication of Greenland.

5. Map of Spitzbergen, from Purchas. (G.M.)

5. Next the English explorers begin to show their handiwork on the charts of the day, and the quantity of delineated Arctic coast fast increases. Purchas, in 1612, published a map of Spitzbergen, showing the whole western and a great part of the northern coast, with the large island of Wiche to the eastward, which afterwards disappeared from our

charts, until it was restored a few years ago. The whales spouting between the meridians of longitude of this old map indicate the wealth which Arctic discoveries were even then bringing to the bold merchant adventurers of Holland and England. Meanwhile Frobisher, Hudson and Davis were extending our knowledge in a westerly direction. The chart of the Zeni was used by Frobisher and Davis, and puzzled them in their discoveries. When the former reached the coast of Greenland he supposed it to be the Frisland of the Zeni, and Davis took it for a new country altogether, calling it "Desolation." Then the inlet discovered by Frobisher north of Hudson's Bay was turned into a strait to the north of "Desolation," leading from the Atlantic to Davis Strait. The Engroenland of the Zeni was placed to the north of Frobisher Strait, and Davis's "Desolation" to the south. Still, with all these errors, the two shores of Davis Strait were correctly delineated.

6. Hudson's map of 1612. (H.S.)

6. Baffin's memorable voyage, in 1616, would have still further extended the knowledge of Arctic geography if his map had been preserved. But, owing to the unwisdom of old Purchas, it was lost to his contemporaries and to posterity. The consequence was that his magnificent discoveries were obscured, and, indeed, almost forgotten until the present century, when his fame was completely vindicated by the voyage of Sir John Ross in 1818 over the same ground.

7. At the opening of the last century, the Dutch seamen and cartographers had corrected and improved the former knowledge, if they had not materially increased it. Van Keulen, in 1707, published an improved map of Spitzbergen, showing, for the first time, the whole of the east coast, the Seven Islands to the north, and the mysterious Gilles Land; but the Wiche Land, discovered by the English in 1617, and shown on the chart of Purchas, has disappeared. Parry, in 1827, bore testimony to the excellence of this delineation of Spitzbergen by Van Keulen. The same able cartographer published a chart

7. The chart of Spitzbergen, by Van Keulen. (G.M.)

of Davis Strait, which was much needed; for between 1715 and 1725 as many as 748 voyages were made in that direction by the Dutch whale-fishers. Their chief fishing station was in Disco

8. Dutch chart of Davis Strait. An English translation, 1731. (A.)

Bay, and the coast of Greenland was well known to them as far as Saunderson's Hope, the furthest point reached by Davis more than a century earlier. We are told that in 1715, Commander L. Feikes Haan sailed along the west coast of Greenland as far north as 72°, where he found the ice solid and immovable. So no sailor succeeded in following the bold track of Baffin during the 18th century; but towards its close, Captain Cook discovered the coast of North America, in Behring Strait, up to Icy Cape; Hearne, in 1772, reached the shores of the Arctic Sea by following the course of the Coppermine; and in 1789 Mackenzie achieved a similar feat when he discovered the river which bears his name.

8. The year 1818 must be considered as the first year of

10. Circum-polar chart, 1818. (R.G.S.)

modern Arctic discoveries; and the careful examination of a map of the Polar regions, prepared in that year before the expeditions sailed, is very instructive. An 1818 chart must be looked upon as our great point of departure, and as the standard by which the progress of discovery in this century may be estimated. The Russians are, it must be confessed, well to the front; for they had already delineated the whole coast of Siberia, and had added to the knowledge of

9. MS. chart with track of Captain Phipps in 1773. (A.)

Novaya Zemlya acquired by the Dutch. The map of Spitzbergen, by Van Keulen, had been slightly improved and added to by Captain Phipps. Davis Strait, and the west coast of Greenland as far as Saunderson's Hope, was well delineated by the Dutch; Hudson's Bay and Strait by the English; but the grand discoveries of Baffin were nearly forgotten, and Baffin's Bay is indicated by a dotted line in the roughest possible manner. On one map of 1818, indeed, we have this legend:—"*Baffin's Bay, according to the relation of*

W. Baffin in 1616, *but not now believed.*" * Except the mouths of the Mackenzie and Coppermine Rivers, the whole coast of Arctic America, from the Icy Cape of Cook to Hudson's Bay, was an absolute blank, as well as the whole space to the northward as far as the Pole.

9. In 1818, Captain John Ross, with Lieutenant Parry as his second in command, sailed on the first scientific Arctic voyage of this century. He followed the track of Baffin almost exactly, and thus vindicated the memory of that great discoverer, replacing all the sounds, headlands, and islands of Baffin † on the chart, and delineating the whole outline of Baffin's Bay. He made an error in supposing that the so-called sounds of Baffin were merely bays, an error which should now be forgotten, while it is remembered that he opened the way to a lucrative whale fishery, and invented an appliance by which he brought samples at depths of a thousand fathoms. It was in Baffin's Bay, when Captain Ross brought up the beautiful *asterophyton* in 73° 30′ N. latitude, that deep-sea sounding and dredging was commenced. A new Arctic bird, the Sabine gull, was also discovered during this voyage. In the same year Captain Buchan and Lieutenant Franklin, with Beechey and Back serving under them, led an expedition to the edge of the polar pack north of Spitzbergen.

11. Chart of Baffin's Bay, by J. Ross. 1819. (A.)

12. MS. chart with track of Captain Buchan, drawn by Beechey. (A.)

10. In 1819 Lieutenant Parry sailed on what was, on the whole, the most successful of all the Arctic voyages. Entering the Lancaster Sound of Baffin, he discovered Barrow Strait, Prince Regent's Inlet, and the east and north coasts of North Somerset, the entrance of Wellington Channel, and the south shores of North Devon, Cornwallis, Bathurst, Byam Martin and Melville Islands, beyond that 110th meridian which secured the

* In Barrington's "Possibility of approaching the North Pole."

† Wolstenholme Sound, Whale Sound, Smith Sound, Jones Sound, Lancaster Sound, Hakluyt Island, Cary Islands, Cape Dudley Digges.

explorers a reward of £5,000. At the western extreme of Melville Island, Parry was stopped by thick and impenetrable ice; but he saw land to the south, which was named Banks Land. In his second voyage, which extended over two winters (1821-23), Parry proceeded in the direction of Hudson's Bay, and discovered the "Hecla and Fury Strait," connecting Hudson's Bay with Prince Regent's Inlet. In the third voyage, of 1824-25, the track of the first voyage was followed; but the season was very unfavourable. Parry was obliged to winter at Port Bowen, on the east coast of Prince Regent's Inlet. In the following season one of his vessels (the *Fury*) was forced on shore and lost, and he returned without any geographical result.

13, 14. Chart of Parry's discoveries. 1819-20. (A.)

15. Chart of Parry's discoveries. Second voyage, 1821-23. (A.)

11. Franklin, Richardson, and Back, in their wonderful land journeys, were tracing the coast line of Arctic America, while Parry made his attempts by sea. In 1819-22 they explored from the mouth of the Coppermine eastward to Cape Turnagain, and in 1825-26 their discoveries extended westward from the mouth of the Mackenzie to Return Reef. In the year 1825 a great combined effort to achieve the North West Passage was planned. Parry was to have proceeded westward from Baffin's Bay, Captain Beechey, in the *Blossom*, was sent to meet him from Behring Strait, while Franklin formed a link, as it were, between the two. Parry's voyage, as we have seen, was a failure. Franklin, approaching Beechey from the Mackenzie river, only got as far as the Return Reef. Beechey himself discovered the portion of the North American coast from the Icy Cape of Captain Cook to Point Barrow. With these attempts in 1825-26 the Government expeditions by Baffin's Bay ceased until Franklin sailed in 1845.

12. Meanwhile, exploring work had proceeded to the east of Greenland. In June 1822 Captain Scoresby forced his way through the ice-floes which encumber the approach to land, and discovered the east coast of Greenland from 75° N. down to 69° N.; and in 1823 Captain Clavering also reached the east

coast, delineating it from 76° to 72°, and enabled Captain Sabine to swing his pendulums at a remote and almost inaccessible spot. Parry's memorable attempt to reach the Pole, by boats and sledges, from Spitzbergen, was made in 1827, when he attained the highest latitude that civilised man has yet been known to have reached, namely, 82° 45′ N. In 1829 the Danish Captain Graah explored the east coast of Greenland from Cape Farewell to 65° 18′, where he was stopped by an insurmountable barrier of ice, and there is still a wide unknown gap on this east coast, between the furthest points of Scoresby and Graah. Captain Graah also made a survey of part of the west coast of Greenland.

16. MS. chart of the north of Spitzbergen, drawn by Foster. (A.)

13. The voyage of Sir John Ross, and his nephew, Commander James C. Ross, was commenced in 1829 in the little *Victory*. They proceeded down Prince Regent's Inlet beyond the point reached by Parry, and discovered the land called Boothia Felix. In land journeys, James Ross explored both the eastern and western shores of this land, and the northern coast of King William Island; but the great event of this expedition was the discovery by James Ross of the position of the North Magnetic Pole in 1831. The Rosses were absent from 1829 to 1833, and in the latter year the explorers, having abandoned their vessel, were picked up by a whaler in Lancaster Sound. Captain Back had, in 1833, undertaken a land journey in search of the Rosses, when he discovered the course of the Great Fish River, and its mouth in the Arctic Sea. Between 1837 and 1839 Messrs. Dease and Simpson almost completed the delineation of the coast of Arctic America. They connected the work of Beechey and Franklin, between Point Barrow and Return Reef, and explored the coast as far as Cape Herschel on King William Island, within a short distance of the position reached by James Ross at Point Victory. Simpson also

17. Graah's charts of Greenland. (R.G.S.) Danish map of Greenland, with Eskimo names. (R.G.S.) Moller's chart of Baal's River and Godthaab. (R.G.S.)

20. Simpson's chart, from Point Barrow to Return Reef. (R.G.S.)

discovered Wollaston and Victoria lands in 1839. Two attempts were made to reach Repulse Bay in ships. Captain Lyon, in the *Griper*, tried it in 1824, by Roe's Welcome, and returned the same season. In 1836 Captain Back made the attempt by Frozen Strait, but was forced to winter in the pack, and crossed the Atlantic in 1837 with his ship, the *Terror*, in a sinking state.

14. During the previous decade the Russians were actively engaged in exploring work. Most of the north coast of Siberia had been gradually examined during the previous century, and the New Siberia Islands were discovered in 1770. But in 1821, Lieutenant Anjou of the Russian Navy undertook their exploration, and he completed a survey of that interesting group. At the same period, Baron Wrangell, from 1820 to 1823, made four journeys on the Polar Sea from Nijni Kolymsk, in dog sledges, exploring the coast from the mouth of the Kolyma to Cape Chelagskoi. Here Wrangell heard of snow-covered mountains visible over the sea to the northward—the land afterwards discovered by Captain Kellett, and subsequently seen by Captain Long. Another Russian expedition was undertaken, in 1843, by Middendorf, who descended the river Khantanga, and sighted Cape Taimyr, getting a view of the Polar Sea.

15. In 1845 the expedition of Sir John Franklin, to make the North West Passage, was dispatched. Since 1818 immense progress had been made, as will be seen by a careful comparison of the chart of 1818 with that of 1845. The state of our knowledge in the latter year was deeply impressed on many minds, for long and anxiously did we ponder over it, in seeking earnestly to conjecture the direction Sir John Franklin would have taken from the point of view of his actual knowledge. In 1845 the whole coast of Arctic America had been discovered from Icy Cape on the west to Cape Herschel on King William Island, and the mouth of the Great Fish River of Back, on the east; but it was not known whether King William Land was

18, 19. Circumpolar chart, 1845. (A.) 1838. (R.G.S.)

21. Facsimile of the chart supplied to Franklin. (R.G.S.)

an island or a peninsula, nor whether Boothia was or was not connected with the main land of America. All to the north was just as Parry had left it in 1820. There was a blank between the south coast of the Parry Islands and the American continent, broken only by indications of land seen by Dease and Simpson, and called Victoria and Wollaston Lands, by the distant coast seen by Parry from Melville Island, and called Banks Land, and by a far off headland south of Cornwallis Island, named by Parry Cape Walker. The northern shores of the Parry Islands were unknown. Baffin's Bay remained as laid down by Sir John Ross in 1818. The east coast of Greenland had not been approached since the time of Scoresby, Clavering, and Graah. Nothing had been done in the direction of Spitzbergen since the voyage of Phipps in 1773; but Admiral Lutke, in 1825, had made a new survey of the east coast of Novaya Zemlya.

16. Sir John Franklin sailed from England in 1845, with the *Erebus* and *Terror*, and, next to Parry in 1819, he made the most remarkable Arctic voyage on record. Passing up Barrow Strait and Wellington Channel, he returned by the strait between Bathurst and Cornwallis Islands, and wintered at Beechey Island. The next year, in accordance with his instructions, he made his way round Cape Walker, and to the south and west, where he was beset in the ice, and his two ships were drifted down, in the pack, and finally stopped to the north of King William Island. Here the brave leader died in June, 1847, and when the survivors set out on their last sad journey, those few who passed Cape Herschel discovered the North West Passage, that is, they proved the continuity of a sea from Baffin's Bay to Behring Strait, by forging the last link in the chain of discoveries. The continuity was thus established. Parry in 1819 found that sea was continuous from Lancaster Sound to Cape Walker, Franklin and his followers from Cape Walker to Cape Herschel, Simpson from Cape Herschel to Point Turnagain, Franklin, Richardson, and Back from Point Turnagain to Return Reef, Simpson from Return Reef to Point

Barrow, and Beechey from Point Barrow to Icy Cape in Behring Strait.

17. The discovery of the widely-extended archipelago, to the north of Arctic America, was completed by the expeditions sent out in search of the *Erebus* and *Terror*. Sir James Ross, in 1848, was the first to make an extended sledge-journey with Lieutenant M'Clintock, and thus to establish the true and only efficient system of Arctic Exploration. Wintering at Port Leopold, he discovered by this means the western coast of North Somerset, as far south as Cape Bird. A general chart shows this discovery, and the state of our knowledge in 1849.

22. Circum-polar charts of 1850. (R.G.S.)

23. Parry Isles and Arctic America, 1850. (A.)

18*a*. In 1850 the expedition under Captain Austin sailed from England, with the *Resolute*, the *Assistance* under Captain Ommanney, the *Pioneer* under Sherard Osborn, the *Intrepid* under Cator; and with M'Clintock, Aldrich, Allen, Browne, Mecham, Vesey Hamilton, M'Dougall, and Clements Markham among the officers. Captain Austin was obliged to winter in the pack, between Griffith and Cornwallis Islands. In the spring of 1851 he organized a comprehensive scheme of search which involved extensive geographical discoveries. M'Clintock reached Melville Island, and visited Parry's Winter Harbour, Aldrich examined the western shore of Bathurst Island, Ommanney and Osborn discovered Prince of Wales Land, and searched its western, while Browne explored its eastern shore, Mecham discovered Russell Island, of which Cape Walker forms the north-east extremity, Vesey Hamilton searched Lowther and Somerville, Allen marched to Garrett Island, and other officers explored the coasts and islands nearer winter quarters. On the voyage home Captain Austin examined the entrance to Jones Sound in Baffin's Bay, correcting the coast-line, and the Cary Islands were visited by the *Assistance*. Thus a very wide extent of new land was discovered by Captain Austin's admirably organized expedition.

24. Track of H.M.S. *Assistance* to the Cary Islands. (A.)

25. Sutherland's circumpolar physical

map, 1851. (R.G.S.) Parry Islands and Arctic America, 1852. (A.) 18*b*. At the same time Mr. Penny, a whaling captain, in command of two brigs, examined both shores of Wellington Channel with sledging-parties, and the veteran, Sir John Ross, in the little *Felix*, sent a party, under Captain Phillips, across Cornwallis Island.

19. In 1851 a private expedition under Mr. Kennedy and Lieutenant Bellot, in the *Prince Albert* schooner, wintered in Batty Bay, on the east coast of North Somerset, and discovered the strait, afterwards called Bellot Strait, which separates North Somerset from Boothia. The northern point of Boothia, on the south shore of this strait, was thus discovered to be the northern extremity of the continent of America.

20. In 1852 the last Government searching expedition sailed, consisting of the *Assistance*, commanded by Sir Edward Belcher, the *Resolute* under Captain Kellett, the *Pioneer* and *Intrepid*, and the *North Star* as a depôt-ship at Beechey Island. Sherard Osborn, M'Clintock, Mecham, and Vesey Hamilton of the former expedition, were also in that of 1852-54, during which M'Clintock and Mecham performed the most wonderful feats in Arctic sledge-travelling on record. M'Clintock discovered the northern shores of Melville and Prince Patrick Islands, and he was the first to find the breeding-place of the ivory gull. Mecham discovered Eglinton Island, with the southern and western shores of Prince Patrick Land. Vesey Hamilton was the discoverer of the northern extreme of Sabine Land, and of Vesey Hamilton and Markham Islands, lying far out in the polar sea. Sherard Osborn and Richards explored the northern sides of Bathurst and Cornwallis Islands. The chief practical result of this expedition was the relief of the *Investigator*, which enabled Captain M'Clure and his officers to make the North West Passage.

21. In 1852 Captain Inglefield went for a summer cruise in the little steamer *Isabel*, and made some surveys which improved the chart of Baffin's Bay. Smith Sound was

28. Chart of Baffin's Bay, with Ingle-

field's corrections. (A.)

found to be an open strait, Whale Sound was also examined, and the intermediate coast-line was laid down more accurately.

22. Simultaneously with the expeditions of Austin and Belcher, searches were instituted from the coast of Arctic America, and by way of Behring Strait. In 1848, the veteran Arctic traveller, Sir John Richardson, conducted a search for his old comrade Franklin, from the mouth of the Mackenzie, to the Coppermine. In 1851, Dr. Rae, a Hudson's Bay Company's Factor, reached the Polar Sea, near the mouth of the Coppermine, crossed Dolphin and Union Strait, and examined the coast of Wollaston Land. In a second journey and voyage, partly by sledge, partly by boat, he examined Victoria Land to the eastward, during August of 1851. During 1854 Dr. Rae was employed to ascertain the connection of Boothia with the American Continent, and thus to join the work of Sir James Ross to that of Parry. This journey also proved that King William Land was an island.

26. Arrowsmith's chart of the Arctic coast examined by Rae. (S.) Arrowsmith's map of discoveries by Rae, north of Repulse Bay. (S.)

23. The voyages in search of Franklin, by way of Behring Strait, were most important in a geographical point of view. In August, 1849, Captain Kellett, in the *Herald*, discovered an island in 72° 51′ N., and 163° 48′ W., with a long range of high land beyond it. In this direction most important discoveries await the enterprise of future explorers, and Captain Kellett's original map well deserves attention.

27. Manuscript charts of Herald Island, with views. (R.G.S.)

24. But the exploits of the *Enterprise* and *Investigator* form the main points of interest as regards discovery from the direction of Behring Strait. Captain M'Clure, in the *Investigator*, rounded Point Barrow in 1850 (the extreme reached by Beechey), sailed westward to Cape Parry, beyond the mouth of the Mackenzie, then stood northward, discovered the southern shore of Parry's Banks Land, and went up the narrow strait, called after the Prince of Wales, between Banks and Prince Albert Lands, until he reached some islands, where the *Investigator* wintered. In

the spring of 1851, sledge parties examined part of the northern side of Prince Albert Land. During the summer the *Investigator* returned to the south point of Banks Island, and then made her way to the northward between the tremendous ice floes and the land, finally reaching the Bay of God's Mercy on the northern coast, beyond which point the gallant ship was never destined to move. M'Clure, his officers, and men, walked over the ice to the *Resolute* at Melville Island, and, returning by Baffin's Bay, were the first to make the North-West Passage, in 1854.

29. Charts of Banks Island, MS. (A.)

25. Meanwhile, in 1851, Captain Collinson in the *Enterprise* also sailed up the Prince of Wales Strait, returning to winter at its southern entrance. In 1852 a party from the *Enterprise* reached Melville Island, and thus also discovered a North-West Passage, by connecting Parry's discoveries with those from Behring Strait. The *Enterprise* then went eastward along the coast of Arctic America, through Dolphin and Union and Dease Straits, and wintered in Cambridge Bay, on the coast of Victoria Land. Captain Collinson, in May, 1853, made a sledge journey still further east, until he reached within a few miles of the position where the *Erebus* and *Terror* were abandoned. The *Enterprise* was forced to pass a third Arctic winter in Camden Bay, east of Point Barrow, and returned home in 1854.

26. The news that Eskimos had tidings of Sir John Franklin's expedition on King William Island, and at the mouth of the Great Fish River, led to the despatch of the *Fox*, under the command of Captain M'Clintock, with the object of finally discovering its fate, and clearing up the mystery which surrounded it. M'Clintock was accompanied by Captain Allen Young. The *Fox* wintered just to the north of the eastern entrance of Bellot Strait in 1858-59, and in the spring of 1859 M'Clintock's great achievement was completed by the discovery of the document which told the sad story of the fate of the *Erebus* and *Terror*. M'Clintock himself made the circuit of King William Island,

while Allen Young discovered the south side of Prince of Wales Land, connecting the discoveries made by officers of Captain Austin's expedition, those of Sherard Osborn on the west with those of Browne on the east. Allen Young also established the existence of a channel leading to Barrow Strait, which is now called Peel Strait.

30. Arrowsmith's chart showing M'Clintock's discoveries, 1860. (R.G.S.)

32. Existing chart of the Parry Islands and Arctic America. (A.)

27. The searching expeditions thus added a vast extent of coast-line to the map of the Arctic regions to the north of America, which will be seen by a comparison of the chart of 1848 with that that is now issued by the Admiralty, of this area.

28. In 1853 Dr. Kane undertook to lead an American expedition up Smith Sound in the northern extremity of Baffin's Bay, in the little brig *Advance*, of 120 tons, with a crew of seventeen men. The means were altogether inadequate for the object in view. Dr. Kane was stopped by the ice only seventeen miles north of the position reached by Captain Inglefield in Smith Sound, and wintered at Van Rensselaer Harbour in 78° 37′ N. In the spring of 1854 Dr. Kane's steward, named Morton, with an Eskimo and dogs, made a journey to the northward along the eastern shore of the strait, to Cape Constitution, in about 80° 56′ N. A second winter was passed in great misery, and, abandoning the vessel, Dr. Kane and his men retreated to the Danish settlements in Greenland, during the summer of 1855.

33. Admiralty chart of Kane's discoveries (R.G.S.)

34. Kane's original MS. chart of his discoveries. (R.G.S.)

29. Five years afterwards, another American expedition started for Smith Sound, under Dr. Hayes, who had served in Kane's expedition. His schooner, the *United States*, of 133 tons, wintered at Port Foulke, in 78° 17′ N.; a few miles within the entrance of Smith Sound; and in the spring of 1861, Dr. Hayes made a sledge journey up the west coast to 81° 35′ N.

30. In the direction of Behring Strait the discovery of land by Captain Kellett was supplemented by Captain Long, in com-

35. Petermann's map of Wrangell Land, 1869. (R.G.S.)

36. Captain Long's chart and sketch of Wrangell Land, 1867. (R.G.S.)

37. Swedish chart of Spitzbergen.

mand of an American whaler, who sailed along the coast of a new land to the north of Siberia, called Wrangell Land, in August, 1867, in about 70° 46′ N. He believed that a steamer might easily have made her way up either the eastern or western sides of this land, and that it was inhabited.

31. The Swedish investigations in Spitzbergen next claim attention. They are comprised in five consecutive expeditions during 1858, 1861, 1864, 1868, and 1872, and have placed the map of that extensive archipelago on a scientific basis. In 1868 the Swedish steamer *Sophia* attained the latitude of 81° 42′ N. in the meridian of 18° E.; and the Swedes pressed further east, on the north coast, than either Phipps or Parry.

38. Petermann's map of Nordenskiold's voyage in 1868. (R.G.S.)

But it is to Professor Mohn of Christiania, who trained the Norwegian fishermen to observe and to report the results of their voyages, that the advancement of geographical knowledge in this direction is chiefly due. Under his auspices, Captain Carlsen circumnavigated Spitzbergen in 1863, in 1864 three Norwegian captains circumnavigated the North-East Land, and in 1872 Captains Altmann and Johnsen re-discovered Wiche Land. The adventurous English yachtsman, Mr. B. Leigh Smith, in 1871, reached the eastern extremity of North-East Land, and his observations gave it a considerable eastward prolongation. He also attained a latitude of 81° 24′ N. In the direction of Novaya Zemlya, the Norwegians have recently

39. Petermann's maps of Novaya Zemlya, showing tracks of Mack, Karlsen, &c., &c. (R.G.S.)

extended our knowledge. In 1869 Carlsen passed through Pet (Jugar) Strait, and sailed along the coast of Siberia to the mouth of the Obi; in 1871 he circumnavigated Novaya Zemlya, while Mack, Johannesen, Tobiesen, and others, explored the sea of Kara, and Rosenthal's steamer *Albert* examined the Matochkin Strait.

32. In the summer of 1868 a small German expedition, led by Captain Koldewey, made a trip to Spitzbergen; and in 1869 the

same commander sailed from Bremen for the east coast of Greenland, with the *Germania* steamer, and a store-ship called the *Hansa*. The latter vessel was caught in the ice, and her crew wintered on the floe, and experienced a remarkable drift almost to Cape Farewell. The *Germania* wintered at the part of the east coast of Greenland, in 74° 30′, which was discovered by Captain Clavering in 1823. In the spring of 1870 Captain Koldewey and Lieutenant Payer made a sledge journey for a hundred and fifty miles to the northward, as far as 77° N., where a grim cape was named after Prince Bismarck. A magnificent fiord, running far into the interior, was also discovered, and in September, 1870, the *Germania* returned to Bremen.

40. Koldewey's track of 1868, by Petermann. (R.G.S.)

41. Discoveries of the German Expedition on the east coast of Greenland. (R.G.S.)

33. The Austro-Hungarian Arctic Expedition, under Captain Weyprecht and Lieutenant Payer, sailed in 1872 in the hope of making the North-East Passage; but their little steamer, the *Tegethoff*, was beset in the ice to the north of Novaya Zemlya, and drifted through the winter of 1872-73. When still beset, they came in sight of a mountainous country on August 31st, 1873, and in October Payer landed on an island in 79° 54′ N. Here a second winter was passed, and in the spring of 1874 Payer, with a sledge crew, started on a journey to explore the newly-discovered country, named Franz Joseph Land. It consisted of three large masses, called respectively Zichy, Wilczek, and Crown Prince Rudolph, with numerous smaller islands. Payer attained a latitude of 82° 5′ N. at Cape Fligely. Finally the explorers were obliged to abandon the *Tegethoff*, and, retreating in their boats, they safely reached the Norwegian port of Vardö in September, 1874.

42. Discovery of Franz Joseph Land. Map by Wayfrecht and Payer. (R.G.S.)

34. In 1870 Captain Hall fitted out a third American expedition for Smith Sound, and sailed in the steamer *Polaris*, of 387 tons, in June, 1871. He entered Smith Sound in August, and took the *Polaris* for two hundred and fifty miles up the strait

43. Map of the "Hypothesis Petermann," abolishing Smith's Strait. (R.G.S.)

leading to the North Pole, now called Robeson Channel, reaching a latitude of 82° 16′ N. on the 30th, where there was a water horizon to the north-east. The *Polaris* wintered at Thank God Bay, in 81° 38′ N., where

44. Polar discoveries of Hall. Washington chart. (R.G.S.) (A.)

Captain Hall died on November 8th, 1871. In the summer of 1872 the *Polaris* was drifted out into Baffin's Bay, and, by an accident, one of the boats, with sixteen souls, including Eskimos, was separated from the ship.

45. Chart of the drift of the *Polaris* boat. Petermann. (R.G.S.)

They drifted on the ice, during the winter, down the whole length of Baffin's Bay, and were eventually picked up off the coast of Labrador in 53° 35′ N. on the 29th of April, 1873. The *Polaris*, with the remainder of the crew, passed the second winter off Littleton Island, near the entrance of Smith Sound.

35. In the summer of 1873 Commander A. H. Markham, R.N., now of H.M.S. *Alert*, undertook a voyage to Baffin's Bay and the Gulf of the Boothia with Captain Adams, in the whaler

46. Track of the *Arctic* in 1873, by Commander A. H. Markham. (G.M.)

Arctic. He obtained several deep-sea soundings, made some corrections in the trend of the coast line on the south side of Barrow Strait, and in Cresswell Bay on the coast of North Somerset, and corrected the position of Point Garry. The *Arctic* brought home the remnant of the crew of the *Polaris*, arriving at Dundee in September, 1873.

36. A recently-published circumpolar chart will show the

47. Circumpolar chart by Stanford. (S.)

48. Track of the *Alert* across the Atlantic. (A.)

51. New Admiralty chart of Baffin's Bay. (A.)

50. Track of the *Alert* from Uper-

results of all these difficult and hazardous voyages and journeys, and will also show how much remains to be done. A vast area is still blank; and it is the object of the Arctic Expedition, which is now enduring the rigours of a winter in the far north, to fill in the most interesting portion, namely, that which intervenes between the present threshold of the unknown region, and the North Pole of our earth. The *Alert* and *Discovery* sailed from Portsmouth on the 29th of May, 1875, and, after a stormy voyage across the Atlantic,

nivik to the Cary Isles. (G.M.)

52. New chart of Smith Sound. (A.)

55. Blank charts for the Arctic Expedition. (A.)

the expedition reached Godhavn on Disco Island, on July 6th, and sailed through the Waigat for Upernivik on the 17th. Thanks to the gallant perseverance of Captain Allen Young, who picked up the letters at the Cary Islands in his yacht *Pandora*, we know further that the Expedition passed easily through the ice of Melville Bay, and proceeded to Smith Sound on July 26th, with every prospect of an open season. The brave explorers will be starting on their long sledge journeys early in April; and they will have the hearty good wishes of their countrymen at home for success in the great national achievement that has been entrusted to them, and for a safe return after the work is accomplished.

CLEMENTS R. MARKHAM.

IV.—Collection of Antarctic Maps.

The selection of maps relating to the Antarctic regions is naturally much smaller than that of the Arctic. The southern regions have never held the same place in public estimation and interest as the northern. The contiguity of the north pole to Europe, from which, in early times, all the trade and commerce of the world emanated, and the importance attached to finding a shorter passage to India and Cathay, to avoid the necessity of rounding the much-dreaded Cape of Storms, all tended to this difference; and although the practicability of a north-west or a north-east passage has long been set at rest, the special interest attached to the North has been maintained.

2. The first voyage on which discoveries were made in the South, was that of the *Good News*, one of five Dutch ships fitted out at Rotterdam in 1599. The vessel was commanded by one Dirk Gerritz, who, in passing south of Cape Horn, reported having seen land, which must have been the islands of South Shetland.*

3. In 1675 La Roche discovered South Georgia.

4. Although Kerguelen Island can scarcely be called Polar land, its latitude in the southern hemisphere being nearly the same as England in the northern, still, where so little was known, it was an important discovery, and the honour is due to the talented, but unfortunate, Frenchman, Yves J. Kerguelen, whose name it bears, and who made two islands off the west coast on the same day (17th January, 1772) that his countryman Marion discovered the island named after himself. Captain James Cook visited the island in his third voyage in 1776—1779. Mr. Robert Rhodes greatly added to our knowledge of the island in 1799, by

* The author has made inquiry as to whether any record of this discovery exists among the archives of the Netherlands Government, but none has been found.

mapping a large portion of the coast; since which, the visits of Captain James Clark Ross in the *Erebus* and *Terror*, Captain Nares in the *Challenger*, and others, have contributed to our knowledge of a large portion of the coast and its harbours.

5. The practical application of the problem of Great Circle Sailing led to the discovery of Heard and McDonald Islands by gentlemen bearing those names, but Captain Heard, of the United States ship *Oriental*, was the discoverer of the group, in November, 1853, and Captain McDonald, of the ship *Samarang*, passed them two months later. Captain Nares, of the *Challenger*, visited the islands in February, 1874, and to him we are indebted for the chart exhibited.

6. The Sandwich group are believed to have been discovered in 1762, and have since been seen by various navigators.

7. Auckland Island was discovered by Bristow in 1806. This island was visited by Ross in 1840, also by the French Expedition under D'Urville the year before.

8. Campbell Island was discovered by Hazleburgh in 1810. This island was also visited by Captain Ross in 1840.

9. It may be mentioned that Captain Cook made no discoveries in the southern seas, although he sailed over such a vast space; but his voyage was of this consequence, that we knew that for any large tract of land we must look farther south than in the parallels of latitude he sailed along.

10. The expedition of the Russian, Bellingshausen, in the *Vostok* and *Mirni*, was, in like manner, not of so much importance from its discoveries as from its non-discoveries. He, like Cook, sailed through a great many degrees of longitude in a high latitude in which no land was seen, although two small islands, Petra and Alexander, were discovered, and those in a higher latitude than any then known.

11. In 1818 Mr. William Smith, of Blyth, re-discovered the land known as South Shetland, also some land to the southward of it. This discovery was confirmed by Mr. Bransfield, R.N., the master

of the Flag-ship on the West Coast of South America; he also discovered another portion of land which he called Bransfield land. This was added to by the discoveries of the French expedition already alluded to in 1838, to which the name of Prince Joinville Land was given, and also still further added to, to the south, by Captain James Clark Ross in 1842-3.

12. The South Orkneys were discovered by Captain George Powell, in the sloop *Dove*, on 6th October, 1821.

13. The remarkable voyage of Weddell, an officer of the Royal Navy, in the *Jane* and the *Beaufoy* sealing vessels, although it did not add to discovery in the southern regions, is well deserving of mention; he penetrated to the extremely high latitude of 74° 15′, which position he reached on the 20th February, 1823.

14. Captain Biscoe, in the employ of that enterprising merchant, Mr. Enderby, in February, 1831, discovered land in the meridian of 50° East longitude, which had the appearance of being a continuous line of mountainous coast: to this he gave the name of his employer.

15. Near this, in 1833, Captain Kemp, in the sealing schooner *Magpie*, discovered another portion of coast to the eastward, which, there can be little doubt, joins to Enderby Land.

16. The year after Captain Biscoe discovered Enderby Land, he discovered an extensive range of land south and west of Shetland Islands, called Graham Land; on this coast Biscoe landed.

17. Another expedition of Mr. Enderby's ships, in 1839, went south, the *Eliza Scott* and *Sabrina*, commanded by Mr. Balleny, and discovered a group of islands, Balleny Islands, in latitude $66\frac{3}{4}$°, and a fortnight after strong appearance of land was noted, and named Sabrina Land.

18. When it is considered with what vessels and means these men braved the dangers of these high and stormy latitudes, and under what circumstances these discoveries were made, the highest praise must be accorded to them for their pluck and perseverance.

and the least the historian can do is to give their names, and suggest the credit due to them.

19. The phenomena of terrestrial magnetism represented by the illustrious Gauss and Weber, gave an impetus to exploration in the southern regions, with the special view of determining the position of the Magnetic Pole, and, in 1839, the *Erebus* and *Terror* were fitted out by Government, and the command given to Captain James Clark Ross for that purpose.

20. Before the expedition under Captain Ross could reach the antipodes, the French expedition under Captain Dumont d'Urville, then in Tasmania, proceeded south, and discovered two portions of land on the Antarctic Circle, which were named "Terre Adelie," and "Coté Clarie."

21. Coincidently with the French expedition, that of the United States, under Lieutenant and Commander Wilkes, proceeded south, and mapped a large tract of land in the latitude of the Antarctic Circle, for which he claimed the discovery; but as a portion of the land had been already seen by Balleny, to him is the honour due; and as the position of a portion of that mapped land was subsequently passed over by Captain Ross at the eastern end, and the *Challenger* failed to see anything of the western end, when within fifteen miles of it on a clear day, the portion added by this expedition to the already discovered land cannot well be ascertained.

22. In November, 1840, Captain Ross left Hobart Town with the *Erebus* and *Terror*, and after visiting Auckland and Campbell Islands, proceeded south, and passing through a belt of pack ice, about 200 miles broad, discovered, on the 11th January, 1841, Victoria Land in latitude 71°. This land was traced to the southward to latitude 78°, where it terminated with the magnificent volcanos Mounts Erebus and Terror, the first named being in a state of eruption. From the eastern point of Mount Terror a wall or barrier of perpendicular ice, from 150 to 200 feet high, extended and was traced about 450 miles, when the ships were necessitated

to return, but not before the position of the southern magnetic pole—the great object of the voyage—had been determined.

23. A second voyage, the following year, did not add to discovery, but the ships attained the highest latitude ever reached, viz., 78° 11′.

24. A third voyage, on the opposite side of the pole, added to the discoveries of Bransfield and D'Urville, to the south of them.

24. The last expedition towards the southern pole has already been alluded to, viz., that of the *Challenger*, in 1874, but Captain Nares made no discoveries in those regions.

J. E. DAVIS.

V.—Collection of Maps of India.

The Figures in Brackets refer to the numbering of the Catalogue.

In a series of maps of India and parts of India from the time of Portuguese ascendancy on the coast to that of the most recent issue from the office of the Surveyor-General, there are illustrations of history, of the progress of cartography, and of the gradually developing and increasing requirements of administration. The rough plans, half picture, half map, are succeeded by more elaborate charts, these by military route surveys, early topographical maps, sheets of the atlas, and finally by elaborate topographical and revenue maps adapted for all the wants of a complicated system of government.

Portuguese ascendancy on the coast is illustrated by a series of very curious and interesting perspective plans of their principal stations, including Goa, Bombay, Cochin, and Quilon (1).

During the long period that the Dutch held sway on the west coast of India very careful surveys were made, which resulted in the beautiful series of maps and charts now preserved at the Hague. These maps are quaintly ornamented, and enriched with carefully executed coloured sketches of towns and forts. There are charts of the Persian Gulf, of Gombroon and Muscat, of the west coast of India, of the Malabar backwaters with soundings, and of the gulf of Manar and Palk Strait, of Cochin, and a series of plans of the forts and factories. Many of them are by that great Dutch cartographer Van Keulen (2).

On the rise of British power the first demand was for charts of coasts, as the base of our operations was the sea. These charts were obtained not more through the early work of marine surveyors, than owing to the indefatigable labours of Alexander Dal-

rymple, the Hydrographer to the East India Company from 1779 to 1808. He not only engraved English charts, but reproduced many hundreds originally published by Van Keulen and other Dutch authors (3). To the French, too, we owe much for the production of the magnificent "Neptune Orièntale," in the last century, by D'Apres de Mannevillette.

But as soon as the English got a footing on shore, and began to extend their influence, demands arose for maps of the provinces, and almost every march of an army resulted in the production of a route survey. It was under the auspices of Warren Hastings, the first Governor-General, that real geographical work was commenced in India. Under him, Major Rennell was engaged on a survey from 1763 to 1782, and in 1779 the famous Bengal Atlas (4) was published by the East India Company, which was followed in 1788 by the Map of India (5). The Map of India by the great French geographer D'Arville had appeared in 1752, and that of Rennell was based upon it, though enriched by much new material.

Colonel Colin Mackenzie was the initiator, in India, of topographical surveys based on triangulation, and was at work in the Madras Presidency from 1783 to 1809 (6). At his suggestion the Madras Military Institution was established under Captain Troyer, and a series of surveying officers received instruction—those who surveyed the greater part of the peninsula of India, and executed a very beautiful series of maps covering the Madras Presidency, between 1811 and 1824 (7). A large scale of survey of the Nizam's Territory was also commenced in 1816, and a number of elaborate maps was the result, which are graphically coloured to show the tanks, irrigated and unirrigated land, and waste (8). These maps were only partially utilised until quite lately, but the remainder are now being lithographed in a style of the first excellence by Mr. Trelawney Saunders (9).

The work of Major Rennell in Bengal was followed by an examination of the whole course of the Ganges, and a desire on

the part of the English officers of that day to explore its sources and the mighty chain of the Himálaya, and to measure some of the highest peaks. In 1800 Lieutenant Wood executed a series of maps of the course of the Ganges from Hurdwar to Allahabad (10); and in 1808 Captain Webb continued the work from Hurdwar up to near the source of the Ganges at Gangotri (11). Route maps were also made, by officers accompanying armies or missions, in Oudh and Rohilcund, in Nepal and Kumaon, in Bundelcund and Bhopal, while a second series of maps of Bengal resulted from Dr. Buchan Hamilton's statistical survey between 1807 and 1814.

As these special maps accumulated the want of a new general map of India soon began to be felt, to supersede those of D'Anville and Rennell. In 1816, Aaron Arrowsmith published his Map of India in nine sheets, on a scale of sixteen miles to an inch, which was the last great general map based on route surveys (12). His subsequent Atlas of South India, published in 1822, was based upon the trigonometrical surveys of Colonel Lambton, filled in by the officers of the Madras Institute. It was in eighteen sheets, extending from Cape Comorin to the River Kistna (13).

By this time the Great Trigonometrical Survey of India had been in progress for twenty years, and the East India Company determined upon the publication of the Indian Atlas, a gigantic undertaking, which is still in progress. The work was entrusted to Mr. John Walker, the eminent engraver, who combined the various documents sent home by the surveyors in India, prepared the sheets for publication, engraved them on copper, and issued them. The Atlas was designed to occupy 177 sheets, on a conical projection, and a scale of four miles to the inch. This scheme embraces the space from Karachi to Singapore, and includes Ceylon. The brass scale, from which all measurements for the copper-plates of the Atlas were taken, is still preserved. The first published sheets were those for which the Madras Surveys furnished the materials, and appeared in 1827 (14). Then followed

one of Bundelcund, from Captain Franklin's work, and the Himálayan region, from the surveys of Hodgson and Herbert, which is now superseded.

The execution of charts from marine surveys, on a trigonometrical basis, soon followed the commencement of similar work on shore. The survey of the Persian Gulf was made between 1820 and 1830, and in the latter year Captain Moresby commenced his famous survey of the Red Sea, which was finished in 1834 (15). Meanwhile, Horsburgh, the author of the East India Directory, had been appointed to succeed Dalrymple, as Hydrographer to the East India Company, in 1810, a post which he held until 1836. Many valuable charts were compiled under his auspices; and Mr. John Walker, as his coadjutor and successor, brought out nearly a hundred, the results of the admirable surveys of the officers of the Indian Navy.

The revenue settlement of the North-West Provinces produced a demand for maps for fiscal and other administrative purposes, and between 1822 and 1842 revenue maps of all the districts were completed (16). Within the same period the first Burmese war led to the acquisition of much valuable geographical information, in the direction of the north-east frontier of Bengal. Captains Bedford, Wilcox, and Burlton explored the valley of the Brahmaputra in 1825, while Captain Pemberton surveyed Munipur and Cachar, and traversed the mountains of Bhutan. All this work was embodied in Pemberton's great map, lithographed at Calcutta in 1838, of the districts on the north-east frontier of India (17).

Thus both peace and war are advantageous to Geography. In the work of the revenue officer and the engineer, as in the operations of an army, surveys are the basis of all progress, and maps are essential.

Under Sir Andrew Waugh, from 1843 to 1861, a great impetus was given to geographical work in India, and in 1851 Colonel Thuillier's publication of the "Official Manual of Surveying" marked an era in the history of Indian cartography. The revenue

maps were extended in one direction to Arracan and the Sunderbunds, in another to the Jullundur Doab. But the most valuable works completed in the time of Sir Andrew Waugh, were the surveys of Kashmir and the Sind Sagar Doab, by Colonels Robinson and Montgomerie.

Colonel Robinson's work comprised the Salt Range, and the whole highland country between the rivers Indus and Jhelum; a region which is the scene of some of the exploits of Alexander the Great, including Taxila, the burial-place of Bucephalus. Here, too, is the line on which India has been invaded from the days of Alexander to those of Nadir Shah. The country abounds in strong positions, and an elaborate and accurate map is important in a strategic point of view, and in facilitating public works operations. The map is in twenty-eight large sheets on a scale of one inch to a mile. The country is most difficult to delineate. It consists of elevated plateaux of marl and clay, resting in basins of sandstone and limestone, supported by the Salt Range, and several parallel ridges which run east and west. These ridges, some of them rising like fish fins, others expanding into mountains nearly ten thousand feet high, protect the surface from denudation; but the country is cut up into a series of deep and intricate ravines (18). Colonel Robinson commenced this survey in 1851, and completed it in 1859. The maps were published by Mr. Walker, and are the most beautiful specimens of his lithography (19).

The topographical survey of Kashmir, under Colonel Montgomerie, proceeded *pari passu* with the main triangulation. It is an admirable piece of work, including the sketching of the wildest and most inaccessible parts of the Himálayas, where the surveyors had to establish stations at heights of 20,000 feet above the sea, and to encounter great dangers and hardships. The maps were executed with taste and skill, and published by Mr. Walker—four sheets on a scale of two miles, and four on a scale of four miles to an inch (20).

In 1867 a Revenue Survey of the Madras Presidency was com-

menced, under Colonel Priestley, an area of 60,000 square miles. It is designed to show the principal variations in the surface of the soil, and all hills, woods, channels, tanks, houses, irrigated and unirrigated land. The village maps are on a scale of 16 inches to the mile, the district maps one inch to the mile, and half an inch to the mile; all the work being connected with the stations of the great Trigonometrical Survey. Up to 1874 eight districts had been completed, 17,941 village maps have been drawn, and 15,607 reproduced by lithography, as well as 79 district maps (21).

Colonel Thuillier succeeded Sir Andrew Waugh as Surveyor-General in 1861; and his energy and talent for organization have been devoted alike to improving the system of surveying in the field, and to making its results more readily accessible to the public. His topographical parties have worked in Central India and Rajputana, in Ganjam and Orissa, and the wild hills bordering on Assam; while the Revenue Surveys range over the North-West and Central Provinces, Oudh, the Punjab, Sind, the Lower Provinces, and British Burma.

In 1866 photo-zincography, under Captain Waterhouse, was introduced into Colonel Thuillier's office at Calcutta, and by this means the out-turn of work has been largely increased (22). Many useful general maps have also been compiled and published. Among them are the map of Punjab and its dependencies in four sections (23); the maps of the North-west Provinces and of Assam (24); and a new standard map of India on a scale of 64 miles to the inch. During 1873 no less than 271,528 copies of maps were struck off, and as many as 5,090 were forwarded to England. This gives some idea of the activity that prevails in Colonel Thuillier's office.

In 1868 the engraving of the remaining sheets of the Indian Atlas was undertaken by Colonel Thuillier, and has since been done at Calcutta (25). Several sheets of the Atlas have already been engraved in India, and are admirably executed by the

English staff, the members of which are also training natives as engravers.

Colonel Walker, who has been Superintendent of the Great Trigonometrical Survey of India since 1861, has combined with the work of triangulation the execution of several valuable topographical surveys, and the production of maps. Under him the Kashmir Survey was completed, an area of 70,000 square miles in every variety of climate and scenery, and there is not a valley in those wild Himálayan regions of perpetual snow that was not visited by the surveyors (26). A topographical survey of Kumaon and Gurhwal was next begun (27), with large scale plans of tea plantations and of hill stations. Surveys were also undertaken in Kattywar and Guzerat of the Bombay Presidency (28), and the maps have since been published (29). In 1867 the Kashmir and Ladak maps were completed, and in 1868 Colonel Walker brought out a valuable map of Turkestan, in four sheets, which has since gone through three editions (30). His assistant, Colonel Montgomerie, has also prepared a series of Trans-Frontier Maps, on a scale of 16 miles to the inch (31), containing all the most recent information beyond the British frontier. They show the positions of towns, villages, rivers, and mountain-passes, but omit the hills.

In the Bombay Presidency cartography has not progressed with the same steadiness and completeness, but there are maps of all the districts, and a useful map of the Sholapore Collectorate has recently been executed, showing by colour the various tenures under which land is held (32). Colonel Laughton also completed, in 1872, the great survey of the town and island of Bombay, which was commenced in 1865—an area of 22 square miles. The scales are 100 feet to an inch for the fields and open country, with 400 feet to an inch for the fort and native town (33). But all the 172 sheets are of one uniform size of 3 feet by 2, and there is also a reduced map in two sheets (34).

The resumption of marine surveys is a very important measure in connection with Indian cartography. Since the abolition of the

Indian navy in 1862, the safety of shipping by the provision of necessary charts had been entirely neglected for many years. At last, in 1874, the work was resumed, and Captain Taylor, R.I.N., was appointed Superintendent of Marine Surveys, with an efficient staff of surveyors, and an admirable draughtsman. The good results are now beginning to appear, and an excellent navigating chart of the west coast of India, from Sonmeani to Vingorla, has already been received.

But Indian cartographic operations have by no means been confined to British territory, as will have been seen from the allusion already made to Colonel Walker's map of Turkestan. The Afghan war led to the production of Mr. Walker's map of Afghanistan, and to a map on a larger scale by the Quarter-Master General's Department. Since then Mesapotamia has been surveyed by the officers of the Indian navy, Persia and Baluchistan by Sir Frederic Goldsmid, Major St. John, and others; while the native explorers despatched by Colonel Montgomerie in various directions over Eastern Turkestan and Tibet have brought back information which has led to the production of very important new maps of portions of those regions (35). In the Geographical Department of the India Office have been produced the interesting map of the Mesapotamian Survey (36), a new six-sheet map of Persia, and a map of Baluchistan by Major St. John (37); while Captain Felix Jones has completed, after some years of labour and research, an exquisitely drawn map of the region between the Mediterranean and Persia, in four sheets, which has not yet been published.

Some efforts have been made as regards India to illustrate statistical and physical facts by means of maps, and the most interesting attempt is that which was made by Mr. Prinsep in a series of maps of the Punjab. He endeavoured to show, by the use of colour, the rainfall, the depth of wells, the area of irrigated and irrigable land, the tenures, and the incidence of taxation (38). In the Reports on the Moral and Material Progress of India for

1871-2 and 1872-3, another beginning of the same kind was made. Maps were furnished showing the rainfall, the distribution of forests, the railways, telegraphs, and lighthouses, the irrigation works, the progress of surveys, and the distribution of troops (39). But almost all subjects can be thus graphically treated on the basis of geographical distribution; agriculture with reference to yield and area of crops, and the proportion of that yield to population; manufactures, institutions, political and ethnographic relations, education, crime, religions, and medical statistics. Such work, to be really satisfactory, cannot, however, precede, but must follow the completion of the surveys in the field.

The Geological Survey, which was commenced in 1851, when Dr. Oldham arrived in India, but not placed on an efficient footing until 1856, has steadily progressed, and will eventually produce a complete geological map of India. The first geological map, compiled from data then existing, was prepared by Mr. Greenough in 1853 (40), and it is still interesting as showing the state of our knowledge at that date. Since the regular commencement of the survey many valuable maps have appeared in the volumes of memoirs, but the publication of the sheets of the atlas geologically coloured is dependent on the progress of the topographical surveys (41). Some sheets have already appeared, and a few years more will see the issue of a general map of the geology of India, which will hold the position which Greenough's map of England, and Griffith's map of Ireland do with reference to general knowledge. This map will, of course, be added to and improved as the country is opened out and examined.

It will have been seen that the supply of Maps of India flows from several sources. The most important, and by far the most prolific, is the office of the Surveyor-General at Calcutta. Here are annually produced new sheets of the Atlas, the results of the topographical and revenue surveys, and many useful compiled maps. Next comes the Head-Quarters of the Superintendent of the Great Trigonometrical Survey at Dehra Dun, where the great

work of calculation and reduction in connection with the trigonometrical survey is done (42). From this source issue the charts of triangulation and of levels, military maps for the use of the camps of exercise, the compilations by Colonels Walker and Montgomerie, and the maps of the topographical surveys of Kumaon, Gurhwal, Kattiwar, and Guzerat. From Madras come Colonel Priestley's village and district maps of the Revenue Survey, and similar work is done at Bombay; while the Marine Survey Department at Calcutta prepares charts for publication by the Admiralty. Lastly, in this country, the Geographical Department of the India Office has the duty of bringing out those sheets of the Indian Atlas which had been commenced before the work was transferred to Calcutta. This Department also occasionally produces and publishes maps under the sanction of the Secretary of State; and, through its agents, utilises the work in India, by bringing it within the reach of students and others, in all parts of the world.

CLEMENTS R. MARKHAM.

GEOLOGY.

THE science of Geology has for its object the investigation of the structure and history of the earth. Starting from a study and comparison of the operations of the great forces whereby terrestrial changes are produced at the present time, such as the movements of the atmosphere, the evaporation, condensation, and precipitation of water, the flow of rivers and glaciers, the distribution of climate, the movements of earthquakes and volcanoes, it inquires likewise into the structure, growth, and geographical distribution of plants and animals. After this preliminary survey of the existing conditions of our planet and its inhabitants, geology proceeds to consider what evidence may be obtainable of changes which have formerly taken place in the inorganic and organic worlds. The materials with which it has to deal in pursuing this investigation are Minerals, Rocks, and Fossils.

Geological research requires apparatus of a comparatively simple kind. This consists of instruments for the determination of specimens, surveying instruments, collections of specimens for analysis and comparison, maps and sections to express the results of surveying, and to furnish data for the elucidation of the geological structure of different districts. To these may be added diagrams, models, and other illustrations whereby the facts and principles of the science may be made generally known and especially available for the purposes of education.

MINERALS, considered as part of the materials of geological

investigation, afford to the geologist information regarding the origin and history of the earth's crust. Leaving their optical properties, crystalline forms, and other characters as the proper subject of mineralogy, he notes their composition as made known by chemical analysis, the positions in which they occur, whether they appear to have been formed contemporaneously with the rocks on which they lie, or to have been subsequently introduced, whether they indicate that water percolating deep within the earth's crust has played a part in their origin, or that they have crystallized from fusion, and how far their substance has been affected by later changes. In the elucidation of these and other questions which minerals suggest to him, he obtains much invaluable assistance from the co-operation of the chemist. But although chemical analysis will carry him a long way in such researches, it cannot reveal to him the inner structure of the crystals, their mode of growth, and the stages of their subsequent alteration—points which, when known, may perhaps help him to explain the history of vast mountain masses of rock. This additional and important knowledge is supplied by microscopical investigation.

The Microscope has now become an essential part of geological apparatus. It appears to have been first used for the examination of thin slices of stone by transmitted light in the year 1829, when W. Nicol, of Edinburgh, cut sections of various fossil woods, and subjected them to scrutiny under the microscope. For this purpose he cemented the polished surface with Canada balsam to glass, and ground the section down until it showed the required degree of transparency. By this method he obtained sections which revealed the minute structure of plants that had been converted into hard siliceous stone, and he showed how the structure of fossil and living plants might be brought into comparison. Little further development of this interesting and important means of research was made until, between 1856 and 1858, Mr. H. C. Sorby, F.R.S., published the results of his application of it to the structure and history of minerals and

rocks. The thin slices which he mounted on glass and placed under the microscope disclosed the presence of minute cavities in various minerals, filled, some with fluid, some with gas or vapour, some with glass or stone. From the nature of the substance contained in these cavities he inferred whether the mineral or rock had been formed from solution in water, from igneous fusion, from sublimation, or from some combination of these. He further pointed out that the fluid cavities were usually not quite full, but contained a little bubble-like vacuity caused probably by the cooling and subsequent contraction of the liquid which at first had filled the cavity; and he argued that either by experiment or calculation it could be ascertained at what temperature and under what pressure the cavities were originally filled. By these observations he originated a new branch of geological research, which in recent years has made great progress. One of the most valuable results obtained by it has been the demonstration of the great part taken by water in the production of the crystalline masses which enter so largely into the structure of the earth's crust. Rocks, like granite, at one time supposed to have originated from direct igneous fusion, have been shown by the microscope to have acquired their present characters under the combined action of the earth's internal heat and subterranean water. Another important feature of the microscopical study of minerals and rocks has been the light cast upon the processes whereby they have been altered, and in some cases completely transformed. Thus it has been ascertained that even in apparently solid and undecomposed rocks water has entered through the pores of the stone, and has effected many changes far into the heart of the mass, introducing some substances, abstracting others, or re-arranging the chemical combinations of the original materials. As this slow percolation of water has been going on since the earliest times, the older the rock is the more may it be expected to show proof of this internal operation. The application of the microscope to geological inquiry promises, therefore, to afford the most material

help in all questions bearing on the mode of origin of minerals, and on the subsequent molecular changes which they have undergone.

Rocks consist of aggregations of one or more minerals. They differ from each other in chemical composition, in texture and structure, in origin and in age. Some have been produced by the consolidation of materials from a molten condition, as, for instance, the lavas of modern volcanoes. Such rocks are for the most part strikingly crystalline; they consist of crystals and crystalline particles of various minerals interlaced and bound together into a compact mass. A second class of rocks has been formed by deposition in water, as sand and mud are laid down at present in lakes and the sea, as lime and iron are deposited by the waters of many springs, or as fragments of shells, corals, and other animals are washed together into a continuous layer on some parts of the ocean bottom. Rocks of this second class show by the fragmentary and usually more or less water-worn aspect of their particles, or by their arrangement in successive layers of deposit the aqueous conditions under which they were formed. A third class unites many of the characters of the first and second series. Some of its members, such as gneiss and schist, seem to have been originally aqueous deposits—sands, gravels, and clays—which being subsequently overlaid by other formations and sinking deep into the mass of the earth's crust, have then been compressed, heated, and crystallized, so as to assume new characters. Such rocks are known as Metamorphic. The whole of the earth's crust, so far as it is accessible to human observation, consists of rocks which may be referred to an Igneous, Aqueous, or Metamorphic series.

The study of the chemical and mineralogical character of rocks forms the branch of Geology termed Petrography. Among the apparatus for its prosecution the first place should probably be given to carefully-selected and well-arranged collections of typical rock specimens. These enable the inquirer to familiarise himself

with the leading features of the already recognised species and varieties of rocks, to compare the rocks of one district with those of another, and to ascertain how far those he may meet with in the field are referable to known varieties. For the first rough or preliminary examination in the field he carries with him, besides his hammer and surveying instruments, a good lens, a pocket knife, and a small acid bottle. This simple apparatus usually suffices for fixing the rocks with which he meets in their proper place, in one or other of the three classes above referred to, and for identifying them with known rocks. For further and more detailed investigation he may avail himself of ordinary chemical analysis. In the identification of ores and other minerals a portable blowpipe apparatus is of great service, but for the study of the minuter structure and composition of rocks the aid of the microscope is indispensable. Thin sections are prepared and mounted in the same way as slices of minerals. Various rock-slicing machines have in recent years been introduced, which are of great service when thin sections cannot otherwise be obtained. Thin slices of rock thus prepared and placed under the microscope, indicate of what minerals a rock consists, how these grew up into the compact mass which they have formed, and what subsequent changes they have undergone. Collections of microscopic preparations of this kind are of considerable value, as furnishing a means for the comparison of the rocks of different countries.

Fossils are the remains of plants and animals imbedded in geological formations. They naturally occur almost wholly in the aqueous rocks, just as at the present day it is in the deposits of rivers, lakes, and seas that the remains of plants and animals are entombed and preserved. At first sight it might seem that the only interest likely to attach to these relics of former life would be such as might arise out of the resemblances or differences found to exist between them and the still living plants and animals of the present time. It has been found, however, that fossils, apart from this source of profound interest, are of the most

essential use in geological investigation, and even in the practical applications of geology. The genius of William Smith first made known, that by means of their fossils the rocks could be identified and followed from district to district, and recognised even on opposite sides of the island. This remarkable conclusion was soon found to hold good among the rocks and fossils of other countries, and gradually the fact came to be firmly established, that in the long past history of our globe, there has been a gradual progress of plant and animal life from low forms in early times up to man in the present. Each particular period has its own tribes of organic forms. And as from the earliest ages, layers of sand, mud, and lime have been formed, and have enclosed and preserved the remains both of plants and animals, so in the deposits of each successive period are found, with more or less completeness, the peculiar and characteristic organic forms of that period. The older deposits lie, of course, below those of later date. When, therefore, the general order of succession has been established, the geologist finds that apart from differences in colour, texture, and composition, the various formations can be distinguished from each other all over the world, by their distinctive fossils. Having acquired this knowledge in a district where the deposits have been little disturbed by subsequent underground movements, he is furnished with a clue to the investigation of those tracts where they have been so fractured and displaced that, but for some such key as is supplied by the fossils, he would probably find it impossible to arrange them in their original and proper order. It is only when the rocks of a district have, in this way, had their chronological sequence determined, that they can properly be compared with those of another region. From arrangements and comparisons of this kind, the geological history of the earth and its inhabitants is in great measure compiled.

But the paramount importance of fossil evidence is not less apparent in the practical applications of geology. Wherever the tracing of a particular deposit or vein depends upon a knowledge

of the relative positions of the rocks, it is of the utmost consequence to attend to the indications furnished by fossils. Suppose, for instance, that among three great series of rocks, which may be called A, B, and C, valuable coal seams existed only in the upper member, C, though in general outward character the whole three series much resembled each other. It would probably be found that the fossils in A differed from those in B, and these again from those in C. In following out the formations into other districts, across intervening seas, lakes, morasses, or obscured ground, or into tracts broken and confused by dislocations and the outpouring of much igneous rock, the geologist might easily become quite at a loss to recognise any of the rocks by outward characters, or to say whereabouts in the geological series his position might be; but if he succeeded in detecting recognisable fossils his difficulties would begin to diminish. If he should encounter a set of rocks with the fossils of A or B he could there entertain no hope of coal, but would know that he was among the formations lying below it. Further search might reward him with traces of the fossils of group C, and he would then feel that, whether or not he should eventually discover the coal, he had, at least, found the equivalents of the series of rocks in which that mineral occurred elsewhere.

Collections of typical fossils, that is, of those which are specially characteristic of particular formations or subdivisions of formations, have therefore an important place, both in the cultivation of original research in geology and in the teaching of the science. When the eye is made familiar with these types it is furnished with a clue to the disentanglement even of the difficult geological structure of an unexplored country. They supply materials for the comparison of extinct forms of plant and animal life with those still existing at the present time; and when they are drawn from different parts of the globe they afford the means of tracing the outlines of the past history of living things upon our planet.

The collection, arrangement, examination, and description of minerals, rocks, and fossils is, however, only a small part of the scope of geological science. A man might be able to recognise their species and varieties and to describe any new kinds he should meet with; he might be a good mineralogist, or an able petrographer, or an excellent authority on the structure of fossil plants and animals, and yet not be in the wider sense a geologist. It is not enough to know the minerals, rocks, and fossils in hand specimens such as can be displayed and examined in museums. The geologist requires to study them as they occur in nature. He finds that in the solid mass of the globe the materials are not thrown together wholly at random, but that certain broad general laws have regulated the accumulation of these materials. He ascertains that the rocks which have been deposited in water lie more or less regularly arranged in parallel beds or layers, and constitute by far the largest part of the solid crust of the earth accessible to observation. He sees that these water-formed strata, as indicated by the remains of plants and animals with which they are abundantly charged, were in some cases formed on land or in fresh water, but in most cases in the sea. Recognising marine shells in rocks now elevated to heights of many thousands of feet above the sea-level, he obtains proof of great upheavals of the earth's surface, and can show that over the sites of even the loftiest mountains the sea has rolled. He further discovers that the oldest rocks of a country have in many cases been upturned before the next series was laid down upon them; that these, again, were disturbed before the deposition of the succeeding series, and thus he can demonstrate that many mountain chains have not been the result of a single movement, but of a long succession of more or less extensive crumplings carried on at wide intervals during a protracted series of geological periods. By the aid of his fossil evidence he can fix the relative dates of these successive upheavals, and can compare the geological age of one mountain range with that of another. He traces, moreover, the existence of numerous frac-

tures by which the rocks of the earth's crust have been dislocated, and can measure the amount of displacement to the extent, sometimes, of many thousand feet. He finds that, as at the present day numerous volcanic orifices exist from which hot vapours, gases, dust, and molten matter are ejected, so in the various epochs of past geological time the earth's surface has been similarly dotted over with active volcanoes. He can follow the course of long-buried lava streams, and, by help of the fossils associated with the beds of compacted dust, can tell whether the eruptions took place on land or sea. He everywhere encounters evidence that the present hills and valleys of the land bear witness in their internal structure to former wholly different conditions of the surface, and in their external outlines to the slow but powerful influence of the rains, frosts, and other agencies by which even the most solid rocks are crumbled into ruin.

That the observations which lead to these and other conclusions of Geology with regard to the past history of the earth may be accurately made, it is needful that geological maps should be constructed to show the actual or inferred arrangement and distribution of the rocks of a district or a country. On these maps the area respectively occupied by the various rocks must be delineated, at the same time the angle and direction of the inclination of the strata, the position, trend, and amount of throw of the dislocations, with such other details as may be requisite to obtain a clear idea of the geological structure of the ground. The most detailed geological maps yet constructed are probably the large sheets of the Geological Survey of Great Britain and Ireland on the scale of six inches to the British statute-mile, or $\frac{1}{10560}$ of nature. Most of the civilised states of the world have organized national geological surveys, primarily to make known their mineral resources, though at the same time usually tending to advance the interests of pure unapplied geology.

In geological surveying, the first essential is the possession of a

trustworthy topographical map on a sufficiently large scale to admit of the more important geological details being entered upon it. This map may either be made by the geologist and his assistants, or by previous topographers. In new countries, such as the unexplored tracts in North America, it is customary to combine ordinary geographical surveying with geological exploration, as in the surveys of Sir William Logan in Canada, and Dr. Hayden among the Rocky Mountains. In long-settled states the production of a good topographical map has for the most part preceded sometimes by a long interval the preparation of a geological one. In Great Britain the Government Geological Survey makes use of the maps of the Ordnance Survey on the scales of 1-inch and 6 inches to the British statute mile. Provided with his map as a groundwork for his own labours, and not encumbered with any work properly devolving on the topographer, the geologist is not burdened with many surveying instruments. His most useful tool is the hammer, which, for the purposes of mapping, ought not to be too heavy; its weight and shape should be so regulated as to secure that just sufficiently large pieces can be broken even from weathered surfaces, to show the true internal character of the rock. He must carry also a small pocket-lens for detecting the minuter textures and crystals of rocks and structure of fossils;—a clinometer for measuring the angles of inclination of strata with the horizon, the most convenient forms being those which are most portable and least liable to get out of order; an azimuth compass for taking bearings and fixing the direction of inclination of strata, the line of faults, dykes, &c. A small protractor to enable him to place these observations accurately on his map; a series of pencils to mark by different colours and signs the position of various formations on the map, and a note-book to contain detailed descriptions written on the spot, and too lengthy to be put on the map. These few portable instruments, which need not be visible on the person of the travelling geologist, suffice to enable him to accomplish the most complex geological surveying.

For the sake of clearness he finds it needful to use upon the map a system of short contractions and signs to express by a few strokes facts and descriptions which would require many words if fully written out, the details being duly entered in his note-book. From time to time the pencillings on the field map are inked over and the different formations are distinguished by washes of colour. The stages in the progress of a field map are illustrated by examples in the collection. When the map of a district or country is completed on a large scale, it may require to be reduced to a smaller size before publication. Thus, in the Geological Survey of Great Britain and Ireland, most of the field maps employed are on the 6-inch scale, which, except for the mineral fields, are reduced and published on the 1-inch scale.

On geological maps, the areas occupied by different rocks are expressed by conventional colours. No general system of colours has yet been adopted; and, perhaps, in the present state of the science, such a system could hardly be proposed. There would, however, be a great advantage in appropriating certain colours or patterns to particular rocks or systems, and retaining them in that application in all countries. The geological map of any country would thus at a glance be generally intelligible to the geologists of other countries. As matters at present stand, each country or state selects its own colours, so that the study of its maps by strangers involves a preliminary and sometimes troublesome process of unlearning the significance of the same colours elsewhere, and of learning another application of them. Where colour printing can be employed, great clearness, diversity, and multiplicity of tints can be obtained.

A perfect geological map should be on such a scale, and with such minuteness of detail, as to contain within itself all the data necessary for the understanding of the geological structure of the area it represents. But in most cases the maps are on too small a scale for this purpose. They are therefore supplemented by sections, wherein the arrangement and thicknesses of the rocks are

depicted as they might appear if deep shafts or long cuttings were made in the ground beneath us. Such sections are either horizontal or vertical, the former showing the geological structure of districts, the latter indicating the order of succession of the rocks at particular places.

Horizontal sections are for the most part generalised diagrams to show the ascertained or inferred arrangement of the rocks between given localities. It is only when they are drawn on a true scale—that is, when the height and length are expressed on the same scale—that they attain their highest excellence. For low countries of very simple geological structure, especially where the rocks are flat, the adoption of a true scale may not be desirable; but for hilly or mountainous ground, where the rocks have been thrown into many different positions, and where the external forms of the surface bear close and evident relation to the internal structure, the preparation of sections on a true scale where practicable, cannot be too strongly recommended. Illustrations of the application of this rule are supplied by the horizontal sections of the Geological Survey of the United Kingdom on the scale of six inches to a mile. These are either levelled on the ground by the officers of the Survey, or plotted from the previous levellings of the Ordnance Surveyors.

Vertical sections either express in a general way the ascertained or inferred succession of formations in a district, or the actual measured subdivisions at a particular locality, as in a coal pit. For the sake of distinctness they are usually drawn to a considerably larger scale than the horizontal sections. It may be added that such further details as cannot be inserted either on map or sections are extended and printed in memoirs or other explanatory text.

It remains to notice the means at present available towards the illustration of geological science for the purposes of teaching. The collection of typical minerals, rocks, and fossils above spoken of, are here of essential service. They may be so selected, pre-

pared, and illustrated as to convey a large amount of information which cannot easily be given by mere written or spoken description. At the same time, by appealing to the eye, they stimulate habits of observation. And apart from their advantage in respect to geological teaching, they have a high value in general education. Geological models are employed with much advantage in making known the main features of geological structure. They may be constructed with the view of specially illustrating such phenomena as faults, or the inclination of strata, or the influence of the irregular superficial removal of rock upon the line of outcrop of strata, or the mode of occurrence of lodes and veins, or the methods of working coal and other minerals. On the other hand, models of particular and instructive districts are sometimes of great value in bringing directly under the eye a combination of geological features which may be readily grasped and understood when so presented, but which could not be adequately realised by the learner on the ground itself. Diagrams, it need hardly be added, form an indispensable part of the apparatus of the teacher of geology. They enable him to supplement his fossil collections and make his pupils realise what were the forms and the structure of extinct plants and animals. By bringing the facts of physical geography and geology graphically before the eye, they not only make them more easily apprehended, but fix them on the memory. A well-devised and clearly-executed series of diagrams can hardly be over-valued as an aid in teaching, and therefore as a means of fostering the development of the science in the future.

A. GEIKIE.

SCIENTIFIC APPARATUS APPLIED IN MINING.

THE multitudinous appliances which are used in the operations of mining may all be termed, in a certain sense, scientific apparatus,—from the rough hammer wielded by manual labour to the mighty steam-engine doing in a small compass the work of five hundred horses. But although the proper construction and application of these numerous instruments depend wholly on scientific principles, they appear to pass out of the category of scientific apparatus, when they are once merged, as implements, in the everyday work of the establishment.

An exception may be made in the case of those instruments which are employed for measuring and registration of directions, of meteorological phenomena, and of numerical problems; but the line of demarcation must nevertheless be a somewhat arbitrary one, which is to separate the objects suitable to the present Exhibition from those examples of the expression of scientific principles in machinery, which would be more in place in an industrial exhibition.

DIALLING APPARATUS.

In determining the linear direction of the veins and other repositories of the useful minerals, and in laying down on paper the position and extent of the workings of mines, the magnetic needle has long been employed. About A.D. 1550, George Agricola (Bauer) describes at full length the construction of the instrument

used for the purpose—a series of five to seven concentric circles, in the middle of which was a depressed receptacle to contain the needle (*magnetinum indicem*). The circles were divided, as is the case to this day with many of the continental dials, into twice twelve parts or "hours." For certain problems, sights were taken upon strings stretched by plummet weights, and a graduated quadrant with plumb-bob (*libella stativa*) was used for the purpose of observing variations of level.

About the middle of the last century the ordinary practice of dialling or subterranean surveying appears to have been carried on with but little change in the apparatus. "The instruments used," says Dr. Pryce,* "are a compass without a gnomon or style, but a centre pin projecting from the middle of the compass to loop a line to, or stick a candle upon, fixed in a box exactly true and level with its surface, about six, eight, or nine inches square, nicely glazed with strong white glass, and a cover suitable to it hung square and level with the upper part of the instrument; a twenty-four inch gauge or two-feet rule, and a string or small cord with a plummet at the end of it; a little stool to place the dial horizontally, and pegs and pins of wood, a piece of chalk, and pen, ink, and paper." A cord was held straight and tight at the ends of the draft, the side of the compass was placed "accurately parallel with the line," and the direction as given by the needle end noted upon paper.

The same author warns "those who take no account of the points or angles of the compass, but in lieu thereof, chalk the bearing of the line they measure with on the board the compass lies in; for if they are not exceedingly careful and precise in their operations, they may commit almost unpardonable and irretrievable blunders: yet formerly, before penmanship and figures were so generally understood and practised among the common tinners as they are at present, most of our mines and adits were dialled for in this manner."

* "Mineralogia Cornubiensis," by W. Pryce. London, 1778.

The dial was soon afterwards fitted with sights, usually made to fold over the compass box, and by means of which the direction of the draft would be taken upon vertical strings, or upon candle flames. A semicircle graduated to twice 90 degrees is often attached in the more modern instruments to one side of the movable sight ring. The great irregularity and frequent lowness of the levels or galleries in metallic mines led to the introduction of the suspension-compass, which is to this day largely employed in continental mining, and has shown itself capable in the hands of careful observers of giving wonderfully accurate results. The cord to which the compass is hung is tightened by screws which have a ring handle, and it is usual, as soon as the line is duly stretched, to take its inclination by aid of a light brass semicircle with a delicately-poised plummet index.*

Coming down into the present century, the rapidly diffused application underground of cast-iron plates and rolled iron rails introduced a new and serious source of inaccuracy into surveys depending on the indications of the needle. Moreover, to say nothing of the working of certain kinds of iron ore, there are numerous mines in which the rock masses are capable of affecting the magnetic needle in a notable degree; and recent researches in microscopic petrology have revealed the presence of magnetite in many places where it was little expected to exist. Hence various forms of the graphometer and theodolite have in the last half century been largely introduced, instruments which, starting from some defined line of bearing, may have the compass needle clamped, and allow a survey to be carried out entirely by determining the horizontal angles by aid of crossed wires in the telescope and of a vernier, enabling the bearing to be read off to thirty seconds.

In the efforts to introduce into the mines an instrument of greater exactness than the old dial or circumferentor, it may be

* *Vide* for figures and full explanation of these instruments, M. Combes, "Exploitation des Mines." Paris, 1845. Lang von Hanstadt, "Anleitung zur Markscheidekunst." Pesth, 1835.

possible in some cases to employ such as also serve for surface surveys, but the requirements of mines in general are such as need a difference of arrangement, especially with a view to portability, and to their being used in narrow or low and tortuous places. M. Combes, the late Professor at the École des Mines, devised a theodolite for underground work, fitted with a telescope attached to a vertical graduated circle for giving the inclinations; and modifications have been made on this, as notably in the excentric theodolite of Messrs. Stackpole of New York, recently described by Professor Vinter, of Columbia College. An important advantage connected with this arrangement is, that we may thus measure any and all vertical angles without being interfered with by the horizontal limb—corrections of course having to be applied for the eccentricity.

The method of supporting the axis of the telescope, like that of a transit instrument, has also been applied underground, as in the transit theodolite of Mr. H. D. Hoskold,* and in the instruments much used in the United States under the term of the engineers' transit. Those made by Heller and Brightly of Philadelphia are described by Professor R. W. Raymond as excellent transits, weighing only 5½lbs., exclusive of the tripod of 3½lbs. The needle is three inches long, and the ring divided to half degrees. A convenient form of plummet lamp is adapted to use with the same instruments, to read off after either sighting upon the strings to which such lamps are suspended, or on bisecting the flame.

It should be added that many good surveys, particularly those of limited areas, are still executed with the miner's dial, and that it is generally recognised that better results are to be had from a rough instrument in practised hands, than from a superior one less skilfully employed. The old suspension-compass has many adherents, and Adolf Plaminek† proposes a new form of it, in

* "A Treatise on Mining and Surveying." H. D. Hoskold. London: Atchley and Co., 1863.

† Berg-und Hüttenmännisches Jahrbuch, bd. xxii. Wien, 1874.

which the azimuth angles are to be read off by aid of a vernier and lens on either side. The graduated ring is divided into hours, degrees, and half-degrees, and, with its attachments to the needle, is of aluminium. If the needle is to be used at all, it is indispensable for accuracy that its many irregularities should be met by due observation and precaution. It is usual in our mines to ignore the secular variation or "declination" of the magnetic needle, and where a plan is comprised of surveys added in successive years, there can thus be no pretension to rigid accuracy. At Przibram, in Bohemia, a meridian line is laid down in the map office (*markscheiderei*); and observations are made several times before and after noon, to determine the diurnal variation, which differing in amount at different localities, may also be a fruitful source of error.

The same compass which has been employed in the survey is upon this system usually fitted into a frame serving the purpose of a protractor, and is thus applied direct to the plotting of the survey on the plan.

In some few cases of uncertain *holing* from one excavation into another, a delicately poised needle has been applied to respond to the action of a powerful magnet on the other side of a rocky barrier. It would be interesting to have particulars of the nature and results of such experiments.

There is, lastly, another application of the magnetic needle—viz., to the discovery of deposits of magnetic iron ore. This in Sweden, where it is often used, is in the form of a dipping needle.

Lighting of Mines.

When towards the end of the eighteenth century great difficulties were experienced in the working of such seams of coal as are termed "fiery," from their giving off fire-damp, many devices of a more or less scientific character were tested for giving light without danger of explosion. The reflection of the daylight on a series of mirrors, the phosphorescence of decaying animal matters,

and the sparks produced by a flint on the rotation of a wheel in the "steel-mill," were all methods of obtaining but a gleam of light, which in particular cases might nevertheless be welcome. The latter apparatus was especially trusted to in many collieries, but was at length, in several instances, proved to have been the cause of an explosion.

The introduction by Sir Humphrey Davy, in 1816, of a cylinder of wire gauze, preventing the flame within from communicating to the explosive atmosphere outside it, established a new era for coal mining. The gauge at first recommended for the safety lamp, 28 wires to the linear inch, or 784 apertures to the square inch, remains that almost universally in use, though variations may be noted in certain districts. The dimensions also remain much the same as those first manufactured on the large scale, although both length and diameter, and therefore the volume of flame which they may sometimes have to contain, are in excess of those in Davy's original trial lamps.

But the number and variety of the safety-lamps which have been produced since that period is so considerable, and many amongst them prove to be so unfitted for practical use, that it may be well in the small space at our disposal only to point out the chief desiderata, and to mention those kinds which have been admitted in large numbers to every day use.

The simple Davy, as was pointed out by its illustrious inventor, is no longer safe if exposed to a current of air of more than five or six feet per second. Recent experiments have shown that with a velocity of eight feet it will pass the flame; and hence if exposed to a strong draught of foul return air, or to a blower, or to the vibration of a wave of air impelled from a considerable distance, it ceases to be a safeguard.* Another objection to the Davy is its insufficient light, offering a premium upon working by unprotected flame.

* See paper by Mr. W. Galloway. Proc. R. Soc., June, 1874, and Trans. North. Inst. Eng.

Dr. Clanny made the lower part of his cylindrical envelope of thick glass; George Stephenson added a cylinder of glass inside that of wire gauze, through the whole length of the lamp, and introduced the air for combustion through very minute holes in the rim under the glass. These types have been taken up and farther modified both in this country and on the Continent, with a variety of results as to the amount of light given and the facility of burning. No other has given as yet so much satisfaction and inspired such confidence as the Mueseler lamp, principally employed in Belgium, and of late years introduced into several works of the largest class in the north of England and in Wales. In it a central conical chimney facilitates an up and a down draught, which cause a brisk combustion and a good light, and thereby remove the temptation to unscrew the lamp-top. It is open, however, to two objections, viz., the passing of the flame at a velocity hardly above that of the Davy, and the fragility of glass, which renders good annealing and care in travelling and in vertical suspension of the lamp very important elements of security.

A multitude of devices for securely locking the lamps, to prevent their being tampered with, and of automatic extinguishers and tell-tale detectors, have been introduced, with more or less success. Thus, superior to the very common form of lock so easily picked is the leaden pin put through the adjoining rims of the upper and lower part of the lamp, and stamped with some device when handed to the men on going to their work; and, again, the magnetic lock exhibited by M. Arnould, of Mons, in Paris, 1867, and now patented by Messrs. Craig and Bidder, in which the top can only be taken off when the lamp is placed on the poles of a powerful magnet. As for the many methods of making the act of unscrewing cause the extinction of the light, they are likely to be of little account as long as men can take lucifers or "safety" matches in their pockets!

Several varieties of lamp have been brought forward since the

experiments and report of a committee appointed by the Northern Institute of Engineers. Some of them have been devised with special reference to further impeding the passage of flame, and have been stated to resist the effect of a current flowing with a velocity as great as forty or fifty feet per second.

Sundry modes of lighting the workings by electricity have from time to time been proposed; but although particular spots occur where something of the kind may be useful, as, perhaps, in a South Staffordshire thick coal working, it may be asserted, with all deference to the ingenuity of the projectors, that such a method of lighting is as a rule inapplicable to extensive collieries.

METEOROLOGY OF MINES.

Underground observations of temperature and barometric pressure have in many cases been carried out from purely abstract scientific motives, but they now form in a great number of our larger collieries an item in the regular daily work with reference to the ventilation, upon which the health and safety of the men depends. For this latter purpose a strong and simple mercurial barometer is ordinarily placed in a cabin or room near the pit-bottom, sure to be often visited by the overman, or sometimes nearly adjoining the ventilating furnace. In the latter position Mr. J. T. Woodhouse commenced above a quarter of a century ago to make it a *sine qua non*, and substituted for the common legend *Fair*, *Rain*, *Stormy*, the hints to the furnace-men, *Fire slow*, *Fire moderate* *Fire heavy*.

Several observant persons have at intervals pointed out the connection between the weather and the condition of the air in mines, and there can be no doubt about some few deductions of deep moment, viz., that the evolution of gas from the face of the workings, as also from blowers, is greater when the atmospheric pressure is less; that when surface temperature increases, the ventilating current becomes more sluggish; and that when, as occurs so commonly, the two changes of depression of barometer and

increase of temperature take place together, the mine experiences at the same time an augmented risk and a diminished power of ventilation. But the relation between explosions and surface storms was not accurately looked into before Mr. T. Dobson in 1855 presented a paper to the British Association at Glasgow. More recently, in 1872, Messrs. R. Scott, F.R.S., and W. Galloway* have shown so important a series of coincidences between colliery explosions in the years 1868, 1869, 1870, and the weather conditions as recorded at Stonyhurst, that they think their evidence justifies the view that "meteorological changes are the proximate causes of a large majority of the accidents."

These instruments should, however, not be kept only in a cabin underground, but should in duplicate be fixed up in some thoroughly visible position in the office at the surface. And since sudden variations, other than those due to depth, of the readings of the one set of instruments from the other may be significant of matters requiring instant attention, an apparatus admitting of comparison between the two may do good service. Thus an increase of temperature beyond a certain limit may be the indication of the approach to an outbreak of "breeding-fire" or spontaneous combustion, and an abnormal decrease of barometric pressure in the main return air-course will be apt to show that some obstruction has taken place in the interior air-ways. Mr. Alan Bagot has recently patented a variety of aneroid barometer and a metallic non-mercurial thermometer which will fulfil the required conditions by signalling, through aid of a battery, as soon as a certain limit either of depression or temperature is attained by the index.

Although practical reasons have interfered with its employment in mines, the ingenious indicator of Mr. Ansell, for calling attention to the presence of fire-damp, even in minute quantities, demands attention as a scientific instrument.

Amongst other instruments which come into play in mining,

* On the connection between Explosions in Collieries and Weather. Proc. Royal Society, 1872, p. 292.

thermometers intended for taking the temperature of the rock and of water may be cited. Of the former, beyond their being of sufficient length, accurately divided, and left for an ample time plugged up in a bore-hole prepared a day or two beforehand, there is perhaps not much to be observed; but when we come to the more debatable ground of deducing the temperature of the rock from observations in deep shafts or bore-holes full of water, the nature of the instrument to be used will require much discussion.

Some of the most notable results of this kind obtained of late years have been those of M. Walferdin, at the bore-hole of Mouille-longe, near Creuzot, and those noted in the unrivalled deep-boring by the Prussian Government, at Sperenberg, near Berlin. In the first of these the maximum thermometer of M. Walferdin was employed, as described in Pouillet's Physique, Paris, 1856, but the observations appear not to have been carried on to the extreme depth of the bore-hole. Those at Sperenberg were made with thermometers on a principle proposed by Magnus,* and constructed by Apel, of Göttingen. In spite of all precautions, some curious anomalies appear among the results, and when we find, in the last instance, a temperature of 118·6° Fahr. at the depth of 4,042 feet, it is only a wonder, considering the ascending and descending currents that are set up in the column of water, that anything so near to a regular scale of increment of heat has been obtained.

Electric Exploders for Firing Shots.

The employment of electricity is as yet somewhat rare among civil miners, although there are, doubtless, many conditions under which it would be desirable to introduce so safe a method of firing charges, especially if they are large or numerous. The battery, the ebonite electric disc, and the magneto-electric machine, with the various fuzes for firing the shot, will form a

* See Pogg. Ann., vols. 98 and 116.

very interesting series for study, but will probably be given with full minuteness of detail under the head of military apparatus.

Ventilation of Mines.

Although the machines and apparatus for promoting the actual ventilation, scarcely come within the limits of the present exhibition, a number of instruments employed for testing its condition, or measuring the actual volume of air in circulation, will constitute an interesting group for study and comparison.

Years ago, and a whiff of powder, or tobacco-smoke, was watched as it floated along a measured length of level in the mine, and then, multiplying the velocity of the current, as thus determined, by the average area of the passage, the total amount passed in a given time was calculated. Mr. Biram, of Earl Fitzwilliam's collieries, appears to have been first to devise a suitable mine anemometer. A number of vanes of a light material, segments of a screw, are arranged upon a horizontal axis in such wise, that being presented broadside to the current of air, the wheel shall make a certain number of revolutions, for so many feet of air passing through it. Thus, if the pitch of the screw be 2 feet, whilst the air passes through 2 feet, the screw or wheel will make one revolution. The number of revolutions, or corresponding number of feet, is registered by indices as a series of circles, and thus on the larger instruments, made 12 inches in diameter, and, indeed, recently in the smaller ones of 6 inches, 4 inches, and even 2 inches in diameter, a continuous self-acting record may be obtained, up to 10,000,000 feet. A vast number of these instruments have been supplied by Messrs. Davis and Son, of Derby; those intended for brief experiment are made to register only a small number; but those which have several dials are intended to record the revolutions for hours and days together, and they are previously tested by the makers at different velocities, and provided with a table of corrections for error.

A small and delicate instrument on a very similar plan is that

which, with its little vanes of aluminium, and its single large recording dial, was brought out as Casella and Lowne's anemometer. A very gentle breath of air will make itself felt on the light sails of this miniature windmill, and it may, therefore, be applied with advantage to test the ventilation of hospitals or other public buildings.

The late Professor John Phillips, of Oxford, proposed many years ago the use of a single vane, which, suspended across the path of the current, should show by its deviation from the vertical the comparative force of the wind blowing upon it. Mr. Dickinson, Inspector of mines in Lancashire, improved upon the instrument by fitting it with a level, a counterpoise, and a graduated arc, upon which may be read off the number of feet per minute at which the current must be travelling, in order to blow out the vane to a certain angle.

A fan anemometer was invented by Professor Combes, of Paris, which it would be interesting to compare in action with our own. It is described in his "Exploitation de Mines," and is now stated to be employed with satisfaction in many of the French collieries. Dr. Robinson's anemometer has not, as far as the writer knows, been employed underground, but the "Electric Velocimeter," lately patented by Mr. F. Pastorelli, follows the same principle so far as regards the relation between the revolutions and the velocity of the wind. But instead of being satisfied with a record kept by index dials attached to the instrument, the inventor transmits the indications to a distance—into the office, if thought desirable, and this renders it possible for a manager to see at all times at what rate his air current is travelling. Each revolution of the cups, in fact, causes a contact to be made, and the receiving instrument, containing an electro-magnet, has upon its face the circles and indices for registering from 10 up to 10,000,000 feet A Leclanche battery of six No. 2 cells is connected with it when the instrument is to be set to work, but may be shut off by the turning of a simple stop.

A smaller instrument, termed a new Portable Air Meter, has also been made by Pastorelli on the same principle as the Robinson cup machine. It will require repeated and careful trials to determine how far this handy little anemometer may prove to rival other kinds which have had the start of it, and also to solve the general problem which of them, seeing that the friction of the air upon the perimeter of the passage renders the results of all of them only approximative, comes nearest to the true average velocity of the current of air.

A very simple piece of apparatus, which does good service when its indications are duly understood and attended to, is the water-gauge. It is usually made in the form of a simple glass U-shaped tube, containing coloured water. One leg communicates with the fresh air, or intake, on one side of a door or partition; the other leg, with the impure air, or return. A greater pressure will act on the water on the intake side than on that of the return air, and the vertical distance between the two surfaces is measured by a scale of inches and parts, which may either be pushed up or down by hand or moved by a screw. It is not, however, as a measure of the ventilation that it is useful, but as an indication of the resistances caused by friction that it becomes valuable. As long as the airways between the two points tested are in good condition, an increase of "water-gauge" would be equivalent to an increase of ventilation, but if an obstruction occurs, as by the fall of shale from the roof, the increase of water-gauge will be an index of increased friction somewhere in the airways, and therefore a call to the exercise of that vigilance which in fiery collieries can never be allowed to rest.

W. W. SMYTH.

CRYSTALLOGRAPHY—MINERALOGY.

THE history of Crystallography, like that of many other of the sciences called inductive, commences almost within the last hundred years. It is the record of the gradual but vigorous growth of a science that shares with Astronomy the privilege of having explained a complicated series of natural phenomena by deducing them from one simple geometrical law. As the character of the motions of celestial bodies is deduced from the law of gravitation, so may that of the polyhedral forms which crystals can assume be anticipated when the rationality of the anharmonic ratios of four tautozonal planes has been asserted as the law of their construction. It will here be only necessary to trace the steps by which this, and the principles of symmetry, physical, as well as morphological, involved in it, came to be established, so far as may serve to show the progressive demand for new and more exact implements for investigation in crystallographic research.

The attempts of Pliny to describe the form of *crystallus* (quartz) and of the *adamas*, leave us without the power of saying what the latter, at least, of these minerals was. In the great sixteenth century, indeed, the idea of attaching significance to the mutual inclination of the faces of crystals first takes shape in the pages of Gesner. But though De la Hire had, early in the seventeenth century, made measurements of crystals, the true father of Crystallography was Romé de Lisle; he first made

systematic use of the contact-goniometer, constructed for him by Carangeot; the instrument that, in the hands of his great rival and successor, Haüy, enormously multiplied the data on which was to be built up a science of Crystallography.

That name, indeed, had been adopted by Romé de Lisle (probably from an earlier work by Capeller), as the title of his treatise *Essai de Cristallographie*, which first appeared a hundred and four years ago; a work which, in a subsequent edition in 1783, assumed the form of a really scientific treatise, and was enriched with the numerous measurements, and the deductions from them, whereby Romé de Lisle established the invariability of the angles of certain simple forms of crystals.

It was Haüy who first sought to establish a general connection between the simplest and other more complex groups of faces shown by crystals. And he reduced their relations to a geometrical shape, referring them to groups, while he recognised the importance of cleavage and of certain physical properties, and left Crystallography a science, while at the same time by its aid he gave a new form to Mineralogy. (*Traité de Minéralogie*, 1801.)

His pupil Weiss, shaking off the molecular hypothesis with which Haüy had trammelled his treatment of the geometry of a crystal, gave to crystallography the power of dealing with its problems from a more abstract point of view. As the originator of the idea, though incomplete, of symmetry in respect to axes as the ruling feature in a crystal, Weiss gave a new standing-point to the science: he designated the crystallographic systems upon this principle, and instituted a mode of crystallographic notation simpler and more easily intelligible than that of Haüy.

In this notation we first (1816) have the faces of a crystal referred, not to its external edges for geometrical comparison, but to *axes* (parallel to certain of these edges) internal to the crystal; while parametral ratios, as we now term them, were recognised in the relative distances along these axes at which some chosen face would intersect them. *Simple coefficients* of these axial lengths, or

parameters, gave the distances at which any and every other face of the crystal would, if continued, meet the axes. Here, therefore, in asserting the integral character of the numbers representing these coefficients (or indices) belonging to every face of the crystal was the fundamental law of crystallography laid down on a purely geometrical basis. Contemporaneously chemistry was asserting an analogous law in the recognition of the integral character and general simplicity of the numbers by which the chemical equivalents are multiplied in combination; and in both sciences the venerable axiom, *Naturâ nihil fit per saltum*, was belied by what appeared in each case to be most simply explicable by the hypothesis of the atomic theory; more strictly perhaps of a molecular theory in the case of the constitution of crystallized matter.

With the progress of crystallographic geometry in the hands of Weiss, and of the great mineralogist Mohs, a more exact instrumental method for determining the angles of crystals became necessary, and this was supplied by the reflective goniometer of Wollaston, the original instrument which, under various and great modifications, is essentially the goniometer of to-day. Wollaston's goniometer consists of a graduated circle on which minutes may be read by aid of a vernier; its centre being penetrated by a double axle, one axle being capable of revolving within the other, so that they can be moved independently or together, the graduated circle being attached to and moving with the outer or hollow axle. In the original instrument the graduated circle moved in a vertical plane: in the form of it employed by Professor W. H. Miller this plane is horizontal. In either case the crystal is supported at the extremity of the prolonged inner axle, and the modes employed for its attachment, support, and adjustment have been various. The measurement of the angle at which two faces of a crystal meet in an edge is effected by bringing into coincidence two signals, one a bright one—preferably a ray of sunlight, to which direction is given by a heliostat—the other a dull one simultaneously seen, the former by reflection from each successive face forming the edge, the latter

by direct vision, the two signals lying in a plane perpendicular to the axis of the instrument, and at the same time to the edge to be measured. The edge has to be accurately adjusted so as to be coincident in direction, and as nearly as may be in position also with the axis of the instrument.

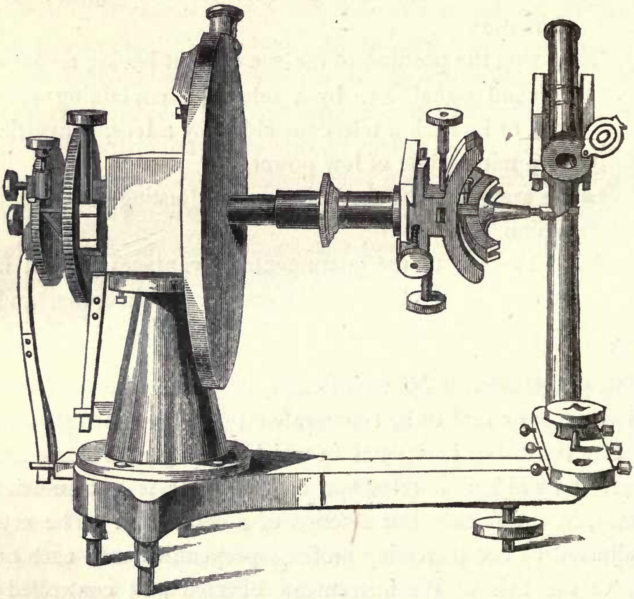
The various modifications which this instrument has undergone have consisted in—

1. Such as affect the arrangements for the signals, *e.g.* by collimators.
2. The fixing the position of the eye without having recourse to a second signal, *e.g.* by a telescope containing crossed wires, or by such a telescope aided by a lens, converting it into a microscope of low power.
3. In the arrangements for fixing and adjusting the crystal in position.
4. And in regard to the instrumental advantages derived from using methods of fine adjustment and clamping, and of regulating all the parts of the instrument itself.

The goniometer of Mitscherlich, as improved by recent modifications, may be said to be represented by the type of instrument, whether vertical or horizontal, in which the signal is single and is observed by aid of a telescope, and, when it is not sufficiently distant, by the further introduction of a collimator. The crystal is adjusted by two traversing motions perpendicular to each other and to the axis of the instrument, effected and controlled by screws, and further by two motions, also perpendicular to each other, in the plane of the axis, best effected by two tangent screws working on the toothed circumference of two segments of concentric circles, lying in perpendicular planes: the crystal edge being approximately at the common centre of these circles.

The latter motions serve to give to the edge to be measured parallelism to the axis of the instrument; the traversing motions place it in coincidence with that axis.

This form of construction, recently adopted in excellent instruments made by Fuess at Berlin, was contrived by Dr. V. von Lang, when on the staff of the British Museum, as an improvement on one previously employed there; and to that crystallographer is also due the means of adjusting the relative positions of the telescope and the crystal along the direction of the axis of the instrument, by moving, not the telescope, but the crystal and its



attendant apparatus of adjustment, which slides along and can be clamped to an accurately turned cylinder of steel, forming the prolongation of the axle of the goniometer. Adjustments for regulating the parallelism of the plane containing the axis of the telescope and the signal, with the plane of the goniometer's disc, and for correcting errors in all other parts of the instrument, render it, without doubt, more or less complex in use; but, when

once properly adjusted, such a goniometer has many of the qualities of an astronomical instrument.

By the addition of certain accessory pieces of apparatus it may be converted into an admirable instrument for determining refractive indices, or for measuring the angle between the optic axes of biaxal crystals.

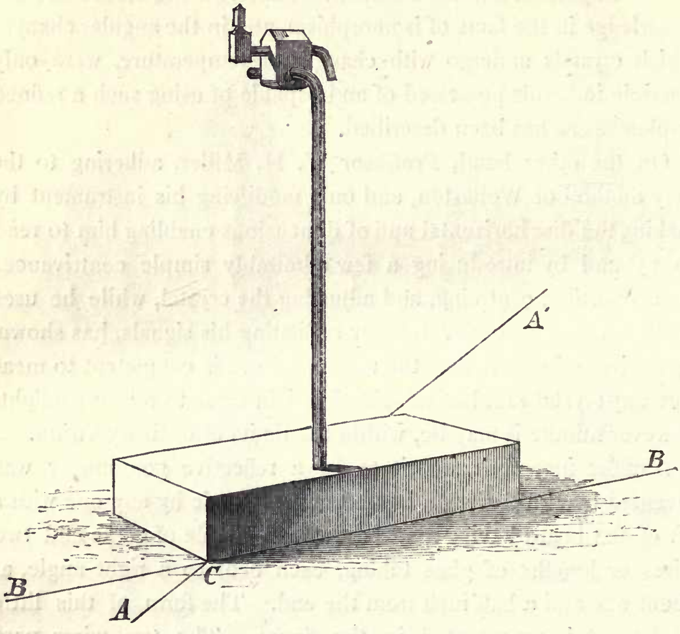
The important additions which Mitscherlich contributed to our knowledge in the facts of isomorphism, and in the angular changes which crystals undergo with changes of temperature, were only possible in hands possessed of and capable of using such a refined implement as has been described.

On the other hand, Professor W. H. Miller, adhering to the very method of Wollaston, and only modifying his instrument by making the disc horizontal and of dimensions enabling him to read to 15′ and by introducing a few admirably simple contrivances for supporting, centreing, and adjusting the crystal, while he uses sunlight only and collimators for regulating his signals, has shown by unrivalled results that the unassisted eye is competent to measure any crystal that has sufficiently bright faces to reflect sunlight, however minute it may be, within the limits of ordinary vision.

A most ingenious substitute for a reflective goniometer was invented by Professor Miller, and may be made by any one with a bit of flat board having a straight side, a couple of corks and two wires or lengths of glass tubing, each bent to a right angle, at about one and a half inch from the end. The form of this little implement is represented in the figure. The two wires pass through holes bored through a cork in perpendicular directions. The tall wire is planted perpendicularly in the block of wood: of the shorter wire (the bent end of which is about three-quarters of an inch in length) the longer arm is passed through the large cork, and, beyond, it penetrates a small cork, into which a pin carrying the crystal may be stuck, or on which the crystal may be fastened with cement.

Two signals, one for direct vision and one to be seen by re-

flection, are now established in the same horizontal plane with the position of the crystal, and the crystal is adjusted in the usual way with the edge to be measured perpendicular to that plane; and the signals are also sighted in the usual manner with one of the faces. A flat sheet of paper having previously been laid under the board carrying the instrument and fixed by weights or pins, a



line A is ruled on the paper along the straight edge of the board. Keeping the crystal as nearly as may be over the same spot, the signals are brought into coincidence for the second face, and a line B ruled as before, intersecting with A in a point C. The angle A C B, in which the two lines, corresponding to the two positions of the instrument, intersect, is that between normals to the faces, and may be determined by the aid of a pair of compasses.

To effect this a circle is drawn through C, and the arc intercepted by A and B on this circle is compared with the whole circumference, equal arcs being measured by their chords; and an approximate common measure of the arcs is found by dividing each successive difference by the next subsequent one, and so determining as nearly as may be desired, by means of a continued fraction the ratio of the arcs; half the arc A B then measures the angle between the faces.

It was to F. E. Neumann, in the first case (1823), that crystallography was indebted for the idea of substituting for the somewhat complex geometry of a number of faces forming a polyhedron the fiction of a sphere described round a point within the crystal, while radii normal to the different faces meet the surface of the sphere in points which are *the poles* of the faces. The recognition of zones of planes, the edges of which are parallel, had already been made by Lévy and by Weiss. Great circles on the sphere of Neumann, along which the poles of tautozonal planes were distributed, could now take the place of zones; and the beautiful work of Grassmann, and subsequently of our great English crystallographer, the Professor of Mineralogy at Cambridge, W. H. Miller, in treating crystallography from this point of view, showed how fertile was this principle in results. Among these were the most simple and comprehensive, yet most complete, notation for *every face* upon a crystal (the notation of C. F. Naumann only designating *forms*, and these often elaborately); and the application of spherical trigonometry to all the ordinary problems of crystallography, and therewith the means of handling the relations of planes in zones and of zones with one another in such a manner as to give the fundamental law of crystallography a new form and a new significance as the rationality of the anharmonic function of any four planes lying in a zone. To Grailich we owe the assertion of the principle of the permanency of zones, and therefore of the type of symmetry of a crystal at all changes of temperature.

Bravais, treating a crystal as a network of molecules, with their

centres of mass distributed at equal distances along parallel and along symmetrically similar directions, drew *à priori* conclusions with regard to the symmetry which it is possible for such a system to present, and even for the necessity of the crystallographic law. Karsten further deduced the necessity of this fundamental law from his geometrical treatment of cohesion. Victor von Lang and Axel Gadolin, independently of each other, deduced results similar to the former of those obtained by Bravais, from the crystallographic law without any molecular hypothesis, though their proofs lacked something of completeness, as well as simplicity. So that now it may be seen that the rules of symmetry, which observers have laid down as those which regulate the forms of crystals, are really but deductions from a simple fundamental law.

But while geometrical crystallography has thus been moving onwards to its goal, the fact that a crystal is not merely a geometrically constructed polyhedron, but that its very form is only one of the results of physical and chemical laws embodied in its material, forced itself on the minds of crystallographers. How largely the science of light already owed to crystal structure, from the days of Huyghens to those of Fresnel, need not be recounted; but the extension of this knowledge from such minerals as Iceland spar and quartz to the whole range of crystallized substances became now the duty of the crystallographer, and instruments and modes of observation proportionately delicate had to be employed. The splendid series of observations by Brewster and Biot early in the century, had already correlated the optical and morphological characters of crystals so far as to show that singly refracting uniaxal and biaxal characters were conterminous with particular crystallographic systems. The observations of Sir J. Herschel and Neumann led to the knowledge that the dispersion of the optic axes (for different wave-lengths) was not symmetrical to an axis except where a mean-line of the optic axes coincided with an axis of morphological symmetry.

The admirable researches of Grailich and Lang, in Vienna, and of Descloizeaux, in Paris, have given to the varieties of dispersion just alluded to very important applications in crystallographic work, and by this means errors into which crystallographers had fallen regarding the systems to which some crystals belong have been corrected.

It is obvious, then, that the impulse thus given to crystallographic physics, and especially the optical section of physics, instituted the necessity for instruments capable of dealing with these problems with considerable precision. The objects of the optical instruments thus required may in general be classed as,—

1. The determination of the optical (uniaxal or biaxal, negative or positive) characters of crystals.

2. The determining the position in them of the optical principal sections, and of the optic axes.

3. The character of the dispersion of these axes for different colours; and,

4. The quantitative determination of the refractive indices, and so of the optical elasticity of the crystal along its principal axes.

As a step preliminary to the use of such instruments, the crystal has to be prepared by the operations of the lapidary in cases where the natural faces do not furnish the surfaces required. A fine saw and a common file, hone-stones with buffs or rubbers offering various kinds of surface, serve to give the requisite shape to sections of such softer crystals as are formed in the laboratory and may be met with in the mineral kingdom. But for the more refractory minerals the instruments of the lapidary have to be used; these are discs of soft iron or steel charged with diamond or emery dust for slitting the crystal, and wheels of pewter charged with coarse emery or diamond dust; plates of various metals, but usually one of brass paved with the finest flour of emery, for working the sections up to a surface, on which the more delicate work of thinning down and finally of

polishing has to be effected by hone-stones, such as "Water of Ayr" stone, succeeded by Turkey-stone or Kansas-stone. The polishing material, however, which has to be employed for finishing the surface varies with the hardness and texture of the substance, and to this experience is the only guide. The friction of the hand, however, under a stream of water generally, where the material is not too refractory, leaves the polish the most complete, and in the case of a rock section maintains the cleanest surface.

Supposing, then, that we are enabled thus to present the crystal in any required form to the process of investigation, we may consider the general character of the instruments by which we are to examine it. Historically we should have to commence with the polariscopes employed by Biot and Brewster in the second and third decades of the century, or the original instrument of Nörrenberg, and those of Dové, Amici, and Soleil, while in variety they would range from the simple tourmaline tongs of the lecture room to the modern polarising microscope of Nörrenberg, or the instrument of Amici as developed in the able hands of Des Cloizeaux. We may be content, however, with alluding only to the more refined sorts of instrument.

The stauroscope of Von Kobell had for its object the determination of the directions of the optical principal sections, on different faces, of crystals, and a means of distinguishing the system to which a crystal might belong. The principle of the instrument is founded on the distortion introduced into the stauroscopic figure presented by an equatorially-cut plate of calcite (seen by somewhat convergent light between two crossed Nicols or tourmalines), when a transparent crystal is placed in the path of the rays in such a position as that its principal sections are not coincident in direction with the axes of the tourmalines (or principal sections of the Nicols). A rotation of the crystal into a position in which this coincidence is established, gives the means of measuring the angle at which its apparent principal sections are inclined on some edge or crystallographic direction, previously determined on

the crystal, and originally placed in a line with the 0°-180° diameter of a graduated circle, by which the motions of the stage carrying the crystal may be read. A more convenient form has been imparted to the instrument by Brézina, who has further increased the delicacy of the method by substituting a compound calcite plate, formed by the symmetrical union of two plates, on each of which the optic axis is slightly inclined to the normals of the plates. The theory of the stauroscope was completely investigated by Grailich. Since in this instrument rays of light nearly parallel have to be employed, it is not immediately applicable to one of the more important uses for which it would be otherwise adapted; namely, for determining the principal sections of the crystals which are presented in the section of a rock as seen in the microscope. Though only approximate results can in the generality of cases be obtained from such microscopic sections, even these are of great importance. Such approximate results may be obtained by applying to the microscope a goniometer eye-piece, in which one wire revolves in the focus of the first lens around the centre of the field, while another wire is fixed in a position parallel to the trace of the plane in which the light is polarised by the polarising Nicol. The position of the fixed wire may be accurately determined by adjusting it in optical coincidence with one of the edges of a very minute crystal of mesotype, or of some orthorhombic mineral presenting an elongated prism, which is mounted on a glass slide and moved by the rotation of the stage of the microscope into such a position that no colour is seen either when the Nicols are crossed or when the analyzer is slightly turned to the right or left. If now a transparent crystal in a rock section in which some crystallographic direction is approximately known, replace in the field the crystal of mesotype, the known line or direction in it can be brought into optical coincidence with the fixed wire in the focus of the eye-piece. Should the light be depolarised by the crystal, this would prove that the determined direction in it must be inclined to its principal sections; since

neither of these will, in that case, coincide with the trace of the plane of primitive polarisation. By the rotation of the stage the crystal may next be brought into a position of maximum obscuration: and after now turning the rotating wire of the eye-piece into a position of optical coincidence or close parallelism to the edge or direction assumed as known in the crystal, we may measure the angle through which the crystal has been moved to effect this result. That angle gives the inclination of the principal sections of the *section of the crystal* to the known crystallographic direction.

The applications of this method are rather more limited than is the case with the stauroscope; but, practically, its chief use is to determine the crystallographic system to which the mineral belongs in cases where that mineral is generally one among a few, the crystallographic and optical characters of which are perfectly familiar to the scientific petrologist.*

The objects sought to be attained under class 1 and class 3 are fulfilled by the improved polarising microscopes of Nörrenberg and of Des Cloizeaux. In these the requirement is to cause a beam of plane polarised light to traverse the portion of the crystal to be examined, which too often is very minute, so as to give the greatest possible difference of path for the ordinary and extraordinary rays within the section, and to obtain the largest possible field. In the French instrument the light is polarised by reflection; in that of Nörrenberg by being made to converge near the middle of a Nicol prism. In the latter the crystal section to be examined is placed on a stage, above and below which a series of lenses, symmetrical in their arrangement as regards the section of the crystal, cause the plane-polarised light to traverse the

* It was by these means that the writer was enabled, by measurements of the inclinations of edges of sections, and recognising the directions relatively to them of cleavage planes, to determine the presence in meteorites of a prismatic mineral other than Olivine, and to which he assigned the characters of Enstatite (or Bronzite) before the presence of the latter minerals had been confirmed by chemical analysis.

crystal in parallel pencils crossing in it at all possible angles; rays of the extreme outer pencils meeting at a very high angle near the centre of the crystal section. On the emergence of the light, it is brought back by the upper series of lenses into the requisite conditions for the interference rings to be viewed by the aid of a lens of low power, between which and the eye the analysing Nicol is placed.

And between the lens and the Nicol can be conveniently placed a $\frac{1}{4}$ undulation plate, or a section of quartz equatorially cut, when needed for the discrimination of positive and negative characters in uniaxal and biaxal crystals.

Instrumental additions to the polarising microscope extend its use to the purposes of a stauroscope, the lenses then being separated so as only to employ the central and approximately parallel rays; or again, where the angle of divergence is not too high, a small graduated disc, as in the instrument of Soleil, allows of measuring the angle between the optic axes. For the latter purpose, however, it is preferable to employ a special instrument, such as the goniometer of Babinet or the improved instrument constructed for the purpose by V. von Lang, which leaves nothing to be desired for accuracy and convenience. The description of the methods of observation requisite for determining the character of the dispersion of the optic axes by the polarising microscope does not fall under our purpose here; and as regards the instruments requisite for determining the refractive indices in crystals, though such instruments must be in the hands of the crystallographer, and may even take the form of adjuncts to his goniometer, the consideration of them really belongs to the more general subject of physical optics.

It will furthermore be sufficient here to make mention of the instruments designed by Haidinger, by Groth, and others, in which all or several of the processes of crystallographic optics that have been alluded to are combined. The dichroscope of Haidinger is an instructive implement for the study of the

variations in the absorption of light of various colours, according to the directions of their vibration in traversing a crystal. The application to this instrument of the methods of spectroscopic investigation has yet to be carried out.

But the recognition that in its physical characters the crystal obeys similar laws of symmetry to those which control its form was not confined to the case of its action on light or heat, or the changes it undergoes with change of temperature. One by one each of the recognised manifestations of force, from the ruder forms of mechanical impact and strain to the subtle influences induced by magnetism and electricity, fell under the law, until it came to be seen that, so far, the symmetry of the crystal belongs to it in all its attributes, as that a plane of symmetry to the form of the crystal was a plane of symmetry to all symmetrically corresponding directions in it for physical characters; that is, as regards the modifications the crystal-matter induces or itself receives under the influence of any force soliciting it. And some of the most remarkable aberrations from the formal principles of symmetry characteristic of a system, in the abeyance and suppression of particular morphological features, have been found to be echoed, as it were, in corresponding peculiarities in crystallo-physical characters. Among these may be instanced the phenomena of pyro-electricity and of rotatory polarisation of light. For establishing these properties of the crystal, observations of the most subtle kind, and physical apparatus proportionately delicate, have had to be employed. They comprise instruments for determining with exactitude changes in the thermic, electric, and magnetic conditions of the crystal, its hardness in different directions (sclerometers), its cohesive power, its mechanical elasticity, and the magnitude and direction of its axes of elasticity. And much of this work has yet to be done, particularly in the more mechanical sections of it.

Hence in passing from optical to other forms of crystallographic research in the domain of physics, such as those dealing with

thermic characters, or with the cohesion, elasticity, magnetic and electric properties of crystals, we should have to consider the modes of using many forms of apparatus which more immediately belong to the department of Physics, and less exclusively to that of Crystallography than is the case in crystallographic optical research.

We may therefore proceed to consider the apparatus necessary for the pursuit of Mineralogy, and especially such as has an educational character.

In so far as the most important fundamental character in a mineral must be recognised in its chemical composition, Mineralogy falls under the domain of Chemistry; and the methods and apparatus of the inorganic chemical analyst equally belong to the two sciences, while their description naturally belongs to that of chemical apparatus. But the importance of Mineralogy to the miner has invested the portable and ready methods for examination of minerals afforded by the blowpipe, and a few physical implements that usually are associated with it, with considerable practical interest, and also with some educational consideration; and Freiberg has long been unrivalled both in teaching these methods and in providing the apparatus for applying them. To the mineralogist, however, still belongs—from the hesitation of chemists in general to appreciate the bearings of Crystallography on their science—the study and the teaching of what may be termed the science of chemical morphology; for to the mineralogist this science is essential.

Admirable models, representing all the varieties of crystal symmetry and crystal form, are now constructed in soft wood and sold for a price that is remarkably low, considering the accuracy with which they are cut. Diagrams illustrating crystallographic forms, and wire models representing the planes of crystallographic symmetry and their axes, or illustrating hypotheses regarding the molecular constitution of crystals, are needed for the intelligent teaching of the subject. Useful also would be representations, whether by diagram or by model, of the optical characteristics of

different systems of crystals, or of other important physical features. Such would be models of the wave surface and of the isothermal ellipsoid in crystals, or in illustration of the different varieties of dispersion. It would, however, be unprofitable to discuss here the various forms which the needs of the lecture-room and the ingenuity of the lecturer might take, in illustrating these subjects.

But one most valuable educational implement remains to be alluded to, namely, the use of collections, typical or otherwise, illustrative of Mineralogy as a classificatory science, or of crystals, natural and artificial, selected with knowledge and discrimination to illustrate salient facts, and the more interesting and exceptional features of Crystallography. Among such illustrative collections would be classed crystal sections cut so as to exhibit the varieties of divergence of the optic axes or of their dispersion, or the influence of heat, strain, &c., on their optical elasticity, or exhibiting the isothermal curves illustrating their conductivity; apparatus and crystals to represent the phenomena of pleiochroism, or the remarkable relations that connect pyro-electric characters, or rotatory polarisation, with peculiarities in the symmetry of the crystals exhibiting these properties.

And for the study of Petrology, a science that can only be properly pursued by a complete mineralogist, microscopic sections of minerals occurring in rocks, and of the different kinds of rocks in which they occur, should be associated with typical collections illustrating either a general series or particular groups of rocks, or those of special localities. And it will be very desirable to see presented before the eye the best lapidaries' implements and accessories to them, for cutting, polishing, and mounting microscopic sections. Good and not necessarily expensive forms of microscope, with means of ready adjustment for the use of polarised light, and of effecting measurements by its aid, and such additions perhaps as may render the spectroscope applicable for simple observations, will also find their place in a complete exhibition of mineralogical and petrological apparatus.

NEVIL S.-MASKELYNE.

BIOLOGICAL APPARATUS.

INSTRUMENTAL appliances of a simple character have been used by students of the Biological Sciences from the earliest times; but the employment of delicate apparatus, and especially of instruments of precision, for the quantitative admeasurement of the forces exerted by living matter, is of comparatively recent date. In fact, the conception of the problems to the investigation of which such apparatus is applicable was impossible until the physical and chemical sciences had reached a high degree of development, and were ready to furnish not only the principles on which the methods of the physiological experimentalist are based, but the instruments with which such inquiries must be conducted.

Of the two principal divisions of biology—namely, morphology and physiology—it is obvious that the former, as a science based upon the observation of the forms and structure of animals and plants, is, by its nature, less dependent upon other branches of knowledge than physiology, which, in the long run, is the application of the laws of physics and chemistry to the explanation of the phenomena of life.

Thus, systematic zoology and botany, so far as they could be founded upon the observation of external forms and rough inspection of internal structure; and even anatomy, so far as it can be carried by unassisted vision, made very considerable progress without other aid than that derived from such ancient and simple instruments as knives, scissors, saws, forceps, pins, and hooks,

Vesalius based his great work on investigations conducted with no better appliances; and it was not until the seventeenth century that the powers of vision on the one hand, and the means of discriminating structures on the other, were artificially enlarged by the help of optical and chemical discoveries.

It is true that the very interesting collection of ancient and modern microscopes in the Collection contains a compound microscope, invented and constructed about the year 1590 (No. 3,513), but it is little more than a toy. The seventeenth century hands down to us the microscopes of Leuwenhoek (3,512), venerable relics of the epoch at which the foundations of minute anatomy were laid; while that of Lyonet (3,525) reminds us that the eighteenth century saw the production of one of the most perfect pieces of minute dissection yet extant—the "Traité anatomique de la Chenille qui ronge le Bois de Saule."

In the hands of Malpighi, Leuwenhoek, Grew, Swammerdam, Lyonet, Hewson, and others, the simple microscope, either as a single lens, or in the doublet or triplet form, did wonders; while Ruysch's exquisite methods of injection showed how the difficulty, not to say impossibility, of tracing out the more minute vessels and ducts of organized structures by mere dissection could be overcome.

Dissection, aided by maceration; microscopic investigation, carried as far as the simple microscope would go, and doubtfully assisted by the imperfect earlier forms of compound microscope; and injection, by the syringe or by the mere weight of mercury,—remained the sole methods of anatomical research up to within the last fifty years.

The improvement of the compound microscope in the early part of this century (see No. 3,526), by the invention of adequate methods of correcting spherical and chromatic aberration, and of illuminating objects, has enabled anatomists to extend their investigations into minute structure to an unhoped-for degree, and to use magnifying powers of 2,000 to 3,000 diameters with as

much confidence as was placed in those of a fourth that amount forty years ago.

Numerous examples of microscopes of the best modern construction are to be seen in the collection, and the contribution which the President of the Microscopical Society has made to this Handbook gives a full account of the principles by which the makers of these exquisite instruments are guided.

Modern histology could hardly have existed, in any shape, without the modern microscope, inasmuch as the meaning of many optical appearances of animal and vegetable structures becomes apparent only under the high magnifying powers and perfect definition of our present instruments. But the precise and definite form which our notions of structure and development have been acquiring during the last ten or fifteen years, is mainly due to the fact that the anatomist has been supplied by the chemist with compounds such as chromic acid, perosmic acid, picric acid, and the like, by which soft organic bodies can be rendered hard enough to be cut into the thinnest slices without alteration of their essential form and arrangement, and by which different elements of the tissues can be made to assume different colours and thus become readily distinguishable.

Hence have arisen various modes of preparing, staining, and slicing organic structures, and many different kinds of instruments adapted for the latter purpose. Very perfect methods of preserving the most delicate microscopic objects have been invented, and the art of injection has been immensely improved both in the completeness of its results and the certainty with which they can be obtained.

In many cases, it is of importance to be able to watch the effects of the application of heat and cold to living objects, and to be able to follow the development of the same microscopic organism for a long period, under conditions which prevent the intrusion of other organisms. Hence the invention of hot and cold stages, of moist chambers, cultivation apparatuses and calorific tables, of which examples are exhibited.

The progress of anthropology has required the accurate determination of the form and dimensions of the various parts of the human body, and attention may be directed to the complete set of appliances for this purpose (No. 3,999).

Important improvements have been made in the arrangements for the exhibition of specimens in museums, and especially in mounting skeletons in such a manner that the separate bones can be detached and examined upon all sides (3,812), and many admirable examples of anatomical and zoological models and diagrams are exhibited.

As it is the object of the physiologist to ascertain the properties and the modes of action of living matter and to explain them, so far as they are explicable, by deduction from the laws of physics and chemistry, he is necessarily dependent upon observations of, and experiments upon, living matter for the data upon which his reasonings are founded.

Among phenomena of so complex a character, simple observation goes but a very little way, and our knowledge of all the most important truths of physiology has been obtained, as the student of the History of Science is well aware, by experimentation upon living plants and living animals.

The older physiologists obtained only qualitative results from their experiments. They determined the nature, but not the amount, of the forces exerted by the tissues; they ascertained the quality and general character of the secretions and excretions, but neither the exact composition nor the precise quantity of the matter secreted or excreted.

The experiments of Hales and of Priestley led the way to quantitative determinations of the effects of physiological processes, but the present generation has seen the greatest advance that has yet been made in physiology—the application of instruments of precision to this end.

From this point of view a singular interest attaches to the

"Muscle-Balance" (3,806) constructed and used, just forty years ago, by the eminent anatomist and physiologist who laid the foundations of Animal Histology.

Du Bois Reymond has said of the experiments conducted by the aid of this apparatus, that they were the first in which a vital force was investigated by physical methods and gave results capable of definite mathematical expression.

No more striking proof of the progress of physiology since 1836 can be found, than is afforded by the numerous and varied instruments for the quantitative determination of functional phenomena of all descriptions gathered together in the present Exhibition.

The relations of electricity to the properties of contractile and nervous substance have led to the employment of the most delicate apparatus of the electrician, as means of physiological investigation; while it is not too much to say, that the introduction of the various forms of registering apparatus has done for physiology what the microscope has effected for anatomy. It has enabled an apparently instantaneous action to be resolved into its successive constituents, just as the microscope has analyzed an apparent point into its co-existing parts; while the elements of the most complex co-ordinated movements have been separately determined, and their relations to one another accurately defined, in a manner comparable to that in which the microscope renders visible the complex arrangement of the histological elements of a tissue, which to the unassisted eye appears homogeneous.

The apparatus by which M. Marey has so successfully investigated the phenomena of animal locomotion, affords an excellent example of physiological appliances of this kind.

The manner in which delicate physical and chemical apparatus is applied to the investigation of such a function as respiration, and to the illustration and explanation of the functions of the higher senses, is well illustrated in the present Collection.

The series of models, collections of specimens, and other

appliances for teaching the biological sciences in schools, are particularly worthy of the attention of all who are interested in education; while the "Plan of the Institute of Vegetable Physiology of the University of Breslau" (3,852) will be especially interesting to English visitors to the Collection, as an example of an institution for the promotion of biological research for which they will at present find no parallel in their own country.

T. H. HUXLEY.

MICROSCOPES.

Microscopes may be divided into two classes, Simple and Compound.

Simple Microscopes.

Simple microscopes consist of one or more lenses, so arranged that the object is viewed directly, and no actual image is formed by one set of lenses, and examined by others, as in the case of compound microscopes.

The utility and so-called magnifying power of a single lens, or of a simple microscope consisting of a combination of lenses, depends solely on the fact that they bend rays proceeding from an object so near to the eyes, that they would not otherwise form a distinct image on the retina, and cause them to enter the pupil parallel or so slightly divergent as to make distinct vision possible.

In the construction and use of lenses two great difficulties present themselves. It is practically almost impossible to make small lenses with any other than spherical curves, and unfortunately simple spherical lenses do not bring the rays to a perfect and exact focus. If it were possible to construct lenses with elliptical or hyperbolic curves, this so-called spherical aberration would be avoided; but, even then, since the different rays of the spectrum are refracted differently, the focal length for red light would be greater than for blue, and it would be impossible to

obtain a sharp image free from false colour. In using simple lenses both the spherical and chromatic aberrations may be reduced by limiting the aperture with a stop, or by using only the central part of the lens; but though we thus gain in definition, we lose in brilliancy.

In order to overcome these difficulties, various combinations of lenses with spherical curves have been adopted, which more or less completely overcome spherical aberration. Such doublet or triplet lenses mounted on a suitable stand have all the advantage of great portability, and since the object is seen in its natural position and not inverted as with a compound microscope, it is much more easy to manipulate or dissect, than when every movement must be made in the reverse direction to that which appears natural. On the contrary, with anything like high powers, the object approaches most inconveniently close to the lenses, and it is trying to the eye to look through the necessarily very small opening, so that, except for particular purposes, there is no doubt that the compound instrument is by far the best form of microscope.

Compound Microscopes.

If a single or double convex lens be held at its focal distance from a lighted candle, an inverted image of the flame may be thrown on a distant wall. Having thus formed such an image, we might magnify it further by looking at it through another lens. But it is not necessary that the image should thus be formed on any material surface. It exists as it were in space, and may be viewed by means of a lens placed beyond the image, in the line of the beam of light. Two simple lenses so arranged, one acting as object glass and the other as eye-piece, would form a rudimentary compound microscope, but with such an arrangement the spherical and chromatic aberrations would be so great that nothing at all like good definition could be obtained. The earliest forms of compound microscopes were constructed on this principle, or

made somewhat less intolerably bad by the use of more lenses than two. The whole instrument was all but unfit for scientific research, and would now be looked upon as very little better than a toy to please those who are amused at seeing a small object look very large, regardless of the accurate definition of minute detail. The theoretical and practical difficulties that had to be overcome in developing the best modern compound microscopes from this embryonic condition were so great that, until within the last fifty or sixty years, the very possibility of success was doubted by the highest authorities in optical science.

Object-Glasses.

Object-glasses should be so constructed that after having passed through the lenses of the eye-pieces used to view the image, all the different rays of light proceeding from a luminous point may enter the pupil of the eye so nearly parallel as to form on the retina an image of the point free from surrounding haze or colour. The possibility of doing this depends on the fact that the extent to which the red and blue rays are separated by passing through different kinds of glass does not vary directly as the extent to which they are bent, or, to use the technical expression, their dispersive power does not vary directly as their refractive power. The result of this is, that we may construct at pleasure direct vision prisms that do not bend the light, but separate the constituent rays of the spectrum, or prisms that bend all the rays at nearly the same very considerable angle, so that though the vision is indirect, the object is free from false colour. This of course is what is necessary in the case of lenses. We require to have the light bent very considerably, and yet not to have the red and blue rays separated by being unequally bent. This is, however, not the only difficulty. The perfect performance of the instrument also depends on the different rays of light being brought to the same focus by both the centre and the circum-

ference of the lenses, since otherwise there can be no perfect focus, and in every position the image must be somewhat indistinct. These various difficulties have been, to a very considerable extent, overcome by using compound lenses, consisting, usually, of a double convex lens of crown glass cemented with Canada balsam to a plano-concave lens of flint glass. When the curves are properly related to the dispersive power of the two different kinds of glass, the unequal refraction of the two extreme ends of the spectrum may be almost overcome, but still the so-called irrational dispersion of glass makes it nearly impossible to obtain an image absolutely free from colour. The spherical aberration may be to a great extent overcome by a proper combination of several of the above-named compound lenses of different sizes, differently corrected. All these difficulties are greatly diminished by reducing the aperture of the lenses and using only their more central portions, but in that case the value of the object glass is greatly diminished from other causes. What is desirable in the abstract is to have an object glass of large aperture, which does not approach too near to the object, and so constructed that when combined with the eye-piece it may give a perfect image free from false colour. The attainment of all these advantages is so extremely difficult in the case of high powers, that even the best object-glasses are little more than the best possible compromises between opposing qualities, and it becomes a question whether lenses of high power should not be designed and made each for a particular class of objects, since a quality which is of paramount importance in one case is not in another. Thus, for instance, in examining some objects it may be far more important to be able to obtain moderately good definition through a considerable thickness of substance, than through a very small thickness to separate lines or markings at very close intervals, whilst it may be the reverse in the case of other objects.

Before passing from the question of object-glasses, it may be well to call attention to one or two points not yet noticed.

Compound lenses of short focal length, properly corrected for viewing an uncovered object, will not be properly corrected when the object is covered with a piece of thin glass. To make the requisite correction such object-glasses are usually provided with a screw-collar, by means of which the front compound lens can be brought nearer to the other, so as to compensate for the effect of the light passing through a greater or less thickness of covering glass. By this means correction may also be made for the effect of increasing the distance between the object-glass and the eye-piece, by drawing out the so-called *draw tube.* This method of increasing the magnifying power is sometimes very useful, but should not be pushed beyond moderate limits, since, strictly speaking, the object-glasses must be corrected for one particular distance between them and the eye-piece. This distance is often made considerably shorter in continental than in English microscopes.

Some object-glasses are made of several independent portions, which can be used alone or combined. The only advantage in such an arrangement is the diminished cost of the instrument; but this advantage is obtained by sacrificing quality, since perfect correction depends on the *combined action of all the lenses*, and on removing one or more, the rest cannot be perfectly correct. When, however, cost is a very important consideration, this principle may be made use of with perhaps better results than could be obtained at the like cost by any other means.

EYE-PIECE.

The eye-pieces of compound microscopes consist of two plano-convex lenses, called respectively the field-glass and the eye-glass —the one, further from the eye, being of very great use in increasing the size of the field of vision, and the one nearer to the eye being instrumental in still further magnifying the enlarged inverted image. Both combined play a very important part in

correcting residual imperfections in the object-glasses, and in giving a flat and even field. The magnifying power of the entire instrument depends in part on that of the eye-lens of the eye-piece; but practically the limit of satisfactory results is soon reached. It is convenient to have two or three eye-pieces of increasing power, but beyond a certain point any increased advantage due to the higher magnifying power is entirely outweighed by loss of light and good definition; and it is far better never to use eye-pieces of very high power, but to employ those of more moderate power in combination with object-glasses of shorter focal length and greater aperture. This, however, necessarily very much increases the cost of the instrument.

In order to overcome the difficulties arising from the inverted image in dissecting under a compound microscope, *erecting glasses* are sometimes used, which give the object in its true position by inverting the image a second time.

BINOCULAR MICROSCOPES.

What is desirable is an instrument with which both eyes can be easily used without any strain, having the field of view down both tubes complete on all sides, with the definition unimpaired, and so constructed that at pleasure the whole of the light can be sent directly up one tube, and the instrument used as an ordinary monocular microscope. In practice it is, however, very difficult, if not impossible, to combine all these advantages, and one or other must generally be sacrificed, according to the taste of the observer or the work with which he is engaged. After passing through the object-glass the light is divided into two portions by means of a prism which reflects one half of the light up an oblique tube, whilst the other passes outside the prism directly up the other tube, or else it is divided by two prisms into two portions, which are deflected up two separate tubes both inclined to the direct line. With this latter arrangement certain

advantages are secured, but the power of converting the instrument at once into a direct simple microscope is lost. The great merits of binocular instruments are that the eyes are less fatigued, and the difference in the level of different parts of an object are far more easily appreciated than with monocular. Solid objects illuminated by surface light are seen in well-marked relief, and even in the case of thin flat sections of transparent substances the general structure is much more readily understood than when only one eye is used. It is also far less trying to the eyes to use both at a time. When only one is employed it suffers from overwork, and the other from underwork, and there is too great a contrast between the use of the eyes when looking through the microscope and when looking at other objects in the ordinary manner. With high powers these advantages are, however, often more than counteracted by loss of light and by imperfect definition over a large part of the field. It is therefore very desirable to be able at pleasure to remove or insert the prism, and employ the instrument monocularly or binocularly, according as circumstances make one or other form most suitable. For certain kinds of work it may be better to forego this power of binocular vision in order to secure other advantages, when the total cost is of importance.

Stand and Stage.

A most important requisite is to have a microscope so constructed that movements affecting it may equally influence both the object-glass and the object; since if either could move in the smallest degree independent of the other, slight and unavoidable tremors would interfere in a most objectionable manner with the use of high magnifying powers. Certain movements are essential or very desirable, but all should be of such a character and so thoroughly well carried out in practice as to withstand a considerable amount of wear and tear without the separate parts becoming loose and giving rise to tremor. It is far better to have no move-

ments which are not absolutely necessary than to have any badly carried out. A roughly-constructed yet complicated instrument is not fitted for practical use. As an almost universal rule, cheap instruments are better to be simple. Assuming that the work is carried out in a satisfactory manner, it does appear desirable that the tube of the microscope should not only be easily moved up and down over a considerable space with power of accurate movement for fine adjustment with high powers, but that there should at all events also be the means of using the instrument either vertically, horizontally, or inclined at any convenient angle. A vertical position is not only inconvenient, but the very worst, for correct definition.

Very much the same general principles will apply in the case of the stage. It is very convenient to be able to move the objects up and down by rack or screw work, and to be able to rotate the stage whilst they always remain in the centre of the field; but if the movements are not well carried out in practice, it is better to have an immovable stage, and to trust to the hand alone in adjusting the object. Very much, however, depends on the nature of the work for which the microscope is designed.

Illuminators.

The proper illumination of objects is of the very highest importance, and that suitable for one class may be altogether unfit for another. Though there may not be any exact line of division between them, yet it is convenient to divide the methods of illumination into three principal divisions; viz., that by reflected, that by transmitted, and that by refracted light.

For opaque objects, reflected light must be used, and even when an object is sufficiently transparent to admit of the use of transmitted light, some characters are better seen by light reflected from the surface. Except for very low powers, this surface illumination must be made sufficiently bright by means either of so-

called "bull's eye" condensing lenses or by curved polished silver reflectors. These latter have the advantage of giving the shadows apparently on the true side, and when made of parabolic form and so fixed that their focus coincides with that of the object glass, the illumination is very satisfactory for many objects. Lieberkuhns differ from such mirrors in reflecting on the object, not the light which passes over it from one side at right angles to the axis of the instrument, but that which passes on each side in the line of the axis. They cannot therefore be used with very large objects, and it is generally necessary to have under the object a dark stop, to prevent any direct light from entering the instrument. Moreover, they throw the light from all sides, so as not to give rise to such well-marked shadows as is desirable. None of these reflectors can be used with very high powers. For them illuminators have been made consisting of a flat plate of thin glass placed above the object-glass, reflecting light down through the lenses, which condense it on the object, and again transmit it to the eye through the reflecting plate of glass. Want of sufficient light is, however, unfortunately the great drawback in the use of very high powers with reflected light, which otherwise would have many advantages, and might enable us to see objects and structures not otherwise distinctly visible.

The possibility of seeing objects by transmitted light depends on their absorbing or bending it in such a way as to give rise to more or less well-defined outlines or markings. One half of the capabilities of the microscope may easily be lost by not illuminating each particular class of objects in a suitable manner. For comparatively low powers, a flat or concave mirror may be used to reflect the light, but for higher powers it is important that the light should be concentrated by means of an achromatic condenser, so adjusted that the rays of light passing on all sides of the object examined may be under the same conditions as those which come from the object itself. For the separation of very close lines with high powers, it is important that the

angle of divergence of the light from the condenser should be nearly equal to, but not greater than, that which can pass into the object-glass, or, in other words, that the angle of aperture of both sets of lenses should be nearly equal, though at the same time there should be the power of modifying this angle by means of a rotating diaphragm with stops of various character. With low powers, a diaphragm of larger size is used under the stage without the condenser. In both cases an aperture that is absolutely necessary to show certain objects distinctly makes others quite invisible. Much the same may be said respecting the value of a so-called *iris* diaphragm, or of one with holes of various sizes fixed under the stage, used without the condenser to limit the width of the beam of light thrown on the object.

For certain cases it is useful to employ light, so transmitted obliquely from below the stage to the under side of the object that the field of the microscope is dark when the object is removed. With such illumination, the structure of the object is shown by light irregularly refracted, or so reflected over and over again that its course is bent from the original oblique angle into that of the axis of the instrument. This kind of illumination by refraction may be obtained by throwing the light obliquely from the ordinary mirror, or by bending it with a prism, or by means of a lens or parabolic reflector with central stops. The latter two give the effect of illumination from all sides, whereas the others give that of illumination from only one side. Each have their own special advantages.

For many purposes no light is equal to that reflected from a white cloud; but since this cannot always be obtained, recourse must be had to lamps of various kinds. The chief requisite in these is to give a bright, white, and steady flame of moderate size. Parallel rays may be advantageously thrown on the mirror of the microscope by means of a bull's-eye condenser, placed so that the flame is nearly in the focus.

Accessory Apparatus.

In addition to those parts of the instrument which are more or less essential for examining nearly all classes of objects, various forms of accessory apparatus are often very useful, or even necessary, for particular purposes. Amongst these, attention may be drawn to micrometers for the stage, or to be inserted into one of the eye-pieces, consisting of plates of glass on which lines are ruled with a diamond at known small intervals. These micrometers are used to determine the true size of objects seen under the microscope, which in some cases it is very important to know. *Live boxes* are used for examining animalcules in water, and *compressoria* for applying more or less pressure to soft tissues. For holding insects and many other objects, various kinds of forceps are used, made so that they can be turned round and moved into different positions. Maltwood's photographed and other *finders* are very useful in enabling us to refer at pleasure to any part of an object previously examined. A camera lucida placed over the eye-piece is employed in making drawings.

Polarising Apparatus, &c.

Minerals and rocks, and even some organic bodies, cannot be studied in a satisfactory manner without the means of examining their action on polarised light. For this purpose a polariser must be fixed below them, and an analyzer above them, over the eye-piece; or, if binocular effects are required, just over the object-glass. Plates of selenite are used to raise or lower the tints of the light caused by the action of the object under examination, and to ascertain whether it has positive or negative double refraction. A double image prism over the eye-piece, and a plate with a round hole inserted into the eye-piece, are very useful in studying the dichroism of minerals. A double image prism goniometer may be employed with advantage to measure the angles of minute crystals.

Apparatus used in preparing Microscopical Objects.

Many of the small tools used in preparing microscopical objects are of such a general nature that they need not be particularised. Attention may, however, be called to the various forms of apparatus used for cutting thin sections of wood, and of similar substances, that can be sliced with a sharp knife, and to those in which arrangements are made for freezing soft, wet animal tissues, and cutting them in a frozen state. Small lathes and wheels are used for cutting, grinding, and polishing sections of rocks, minerals, fossils, shells, and other similar more or less hard and brittle substances. These may save time and material, but are by no means essential, since first-rate sections may be prepared by holding the objects in the hand, and grinding them down on flat metallic plates, with somewhat coarse and finer emery, and finishing them off on flat stones of various quality.

Spectrum Apparatus.

The more accurate study, by means of spectrum analysis, of the exact nature of the light transmitted by, or reflected from, coloured substances, has led to the introduction of a number of new forms of accessory apparatus. The analysis of the light is effected either by means of a special spectrum eye-piece, having the slit at the focal point of an achromatic eyeglass, over which is placed a compound direct-vision prism, or by means of apparatus having the slit at the focal point of the object-glass. The former class of apparatus is far the most suitable for the examination of very minute objects with high powers, since they are in focus along with the spectrum, whereas a form of apparatus, placed below a special object-glass of long focal length, is far more convenient in studying with a binocular microscope the spectra of solutions held in small glass cells, or of any objects not less than one-eighth of an inch in diameter, which need not be exactly in

focus. In both forms of apparatus the spectra of two different objects can be compared together, side by side. This is a most important requisite, though the means of doing it has occasionally been omitted in some forms of apparatus. In addition to the essential spectrum part of the instrument, various accessory contrivances have been made to enable an observer to accurately measure the position of any particular part of the spectrum, and to determine the wave-length of the light at each part.

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